Public Works Canada
Travaux publics Canada

Architectural and Engineering Services
Services d'architecture et de génie

Building Performance Evaluation Series

Illumination Evaluation

Document D10

Canada

Building Performance Evaluation Series

Illumination Evaluation

Document D10

AES 1-4:86-30

March 1988

The Minister of Public Works makes no representation or warranty, express or implied, with respect to this publication or the programs or information described in this publication, their quality, merchantability, or fitness for any particular purpose, or their adequacy to produce any particular result. In no event shall the Minister or Her Majesty the Queen in right of Canada, Her employees, servants or agents be legally liable to any person or persons for any damage, whether direct, indirect or consequential, resulting from the use of said publication or the programs or the information contained therein.

Published by Architectural and Engineering Services
Public Works Canada

Public Works Canada / Travaux publics Canada

DOCUMENT DATA

1. Document Title ILLUMINATION EVALUATION	2. Control Number AES/SAG 1-4:86-30
	3. Date March 1988
4. Author(s) I. Pasini	5. Consultant's Ref. No.
6. Project Manager	7. Discipline Series No. D10
8. Preparation Agency and Address Building Performance Division, Public Works Canada Room C-548, Sir Charles Tupper Building Riverside Drive, Ottawa, Ontario, K1A 0M2 Telephone: (613) 998-7830	9. Document Type Guideline
	10. No. of Pages 198
11. Sponsoring Agency and Address D.C. and R.T. Appropriated Programs Accommodation Branch	12. PWC File No. A4270-16
	13. PWC Project No. 602055
14. Supplementary Notes Questions and comments should be directed to the preparation agency, in 8 above.	15. SSC Publication No.
	16. ISBN

17. Abstract

This document provides methods for assessing the illuminated environment of office buildings. Interiors, exteriors, electric lighting and daylighting are all discussed with techniques given for their analysis. The three stages of assessment described are discussed in terms of both quantity and quality issues.

Issues addressed include: light source efficacy, reflectance and transmittance of materials, luminance and illuminance surveys, daylighting issues and surveys, contrast, visual performance, lighting control strategies, maintenance, VDT areas, energy audits, photometric data, laboratory testing, and emergency lighting.

The appendices contain detailed survey methods along with examples and reference tables.

18. Distribution Statement Copies are available from: Documentation Centre Architectural & Engineering Services Public Works Canada Sir Charles Tupper Bldg., Riverside Dr. Ottawa, Ontario K1A 0M2	19. Keywords	
	20. Documentation Centre Catalogue No. BP D10e	21. Price

Travaux publics Canada | Public Works Canada

FICHE SIGNALÉTIQUE DE DOCUMENT

1. Titre du document ÉVALUATION DE L'ÉCLAIRAGE	2. Numéro de contrôle AES/SAG 1-4:86-30
	3. Date mars 1988
4. Auteur(s) I. Pasini	5. No de réf. du conseil
6. Chargé de projet	7. No de la collection technique D10
8. Nom et adresse de l'organisme rédacteur Division du rendement des immeubles, T.P.C. Local C-548, Édifice Sir Charles Tupper Promenade Riverside, Ottawa, Ontario, K1A 0M2 Téléphone: (613) 998-7830	9. Type de document Lignes directrices
	10. Nombre de pages 203
11. Nom et adresse de l'organisme promoteur Technologie du design, de la construction et de l'immobilier Programmes de soutien à la gestion immobilière fédérale Logement	12. No de dossier de TPC A4270-16
	13. No de projet de TPC 602055
14. Notes Toutes questions ou commentaires doivent être dirigés à l'organisme rédacteur, se référer à 8 ci-haut.	15. No de publication de ASC
	16. ISBN

17. Résumé

Ce document renferme les méthodes d'évaluation des espaces éclairés d'immeubles à bureaux. Il traite des espaces intérieurs et extérieurs du l'éclairage électrique et naturel, et présente les techniques d'analyse connexes. Dans les trois étapes d'évaluation, on tient compte des aspects quantitatifs et qualitatifs.

Voici les sujets abordés : l'efficacité des sources de lumière, les facteurs de réflexion et de transmission des matériaux, les études de luminance et d'éclairement, les problèmes de l'éclairage naturel et les études connexes, le contraste, la performance visuelle, les techniques de commande de l'éclairage, l'entretien, les zones à terminaux à écran de visualisation, les études de la consommation d'énergie, les données photométriques, les essais en laboratoire et l'éclairage de secours.

Les annexes renferment toutes les méthodes d'étude détaillées ainsi que des exemples et des tableaux de référence.

18. Diffusion Exemplaires disponibles: Centre de documentation Services d'architecture et de génie Travaux publics Canada Édifice Sir Charles Tupper Promenade Riverside Ottawa, Ontario K1A 0M2	19. Mots clés	
	20. No de catalogue du centre de documentation BP D10f	21. Prix

TABLE OF CONTENTS

1.	**INTRODUCTION**	1
1.1	Purpose and Objectives	1
1.2	Background Information	1
2.	**TERMS OF REFERENCE**	2
2.1	General Framework	2
2.2	Limitations of Evaluation Techniques	2
3.	**METHODOLOGY**	4
3.1	Stage I – Preliminary Assessment	4
3.1.1	Description of Technique	4
3.1.2	Equipment/Material	4
3.1.3	Detailed Procedures	4
3.1.3.1	Plan and Archive Review	4
3.1.3.2	The Building Walkthrough	7
3.1.4	Assessment Procedures	8
3.1.4.1	Quantitative Assessment of Electric Lighting	8
3.1.4.2	Quantitative Assessment of Daylighting	9
3.1.4.3	Qualitative Assessment of Electric Lighting and Daylighting	9
3.1.5	Resource Allocation and Timing	10
3.2	Stage II – Simple Measurement Techniques	10
3.2.1	Description of Technique	10
3.2.2	Equipment/Material	11
3.2.3	Detailed Procedures	11
3.2.3.1	Lighting Quantity: Efficacy	11
3.2.3.2	Lighting Quantity: Illuminance Levels	11
3.2.3.3	Lighting Quantity: Illuminance Uniformity Ratios	12
3.2.3.4	Lighting Quantity: Average Daylighting Factor	12
3.2.3.5	Lighting Quality: Reflectance and Transmittance	12
3.2.3.6	Lighting Quality: Luminance of Surfaces	13
3.2.3.7	Lighting Quality: Luminance Ratios	13
3.2.3.8	Lighting Quality: Light Source Intensity	13
3.2.3.9	Lighting Quality: Contrast	13
3.2.3.10	Lighting Quality: Visual Performance	13
3.2.3.11	Lighting Quality: Lighting Control Strategies	14
3.2.3.12	Lighting Quality: Lighting Maintenance Program	14
3.2.3.13	Lighting Quality: VDT Areas	15
3.2.3.14	Building Energy Audit	15

3.2.4	Assessment Procedures	16
3.2.4.1	Quantitative Assessment of Electric Lighting and Daylighting	16
3.2.4.2	Qualitative Assessment of Electric Lighting and Daylighting	16
3.2.4.3	Building Energy Audit Assessment	16
3.2.5	Resource Allocation and Timing	17
3.3	Stage III - Specialized In-depth Monitoring	17
3.3.1	Description of Technique	17
3.3.2	Equipment/Material	17
3.3.3	Detailed Procedure	18
3.3.3.1	Accurate Occupancy Patterns	18
3.3.3.2	Visual Performance Parameters	18
3.3.3.3	Sophisticated Luminance Surveys	18
3.3.3.4	Complex Surveys of VDT Environments	18
3.3.3.5	Long Term Complex Daylighting Surveys	19
3.3.3.6	Daylighting Evaluation by Models	19
3.3.3.7	Photometric Testing and Analysis	19
3.3.3.8	Pilot Studies	20
3.3.4	Assessment Procedure	20
3.3.4.1	Quantitative Assessment of Daylighting and Electric Lighting	20
3.3.4.2	Qualitative Assessment of Electric Lighting and Daylighting	21
3.3.5	Resource Allocation and Timing	21
4.	**REFERENCES**	22
5.	**APPENDICES**	23
5.1	Standard Terms and Units of Measurement	23
5.2	Governing Authorities, Regulations and Guidelines	26
5.3	Reference Lighting Tables	34
5.3.1	Introduction	34
5.3.2	Luminance Tables	34
5.3.3	Room Finishes	36
5.3.4	Typical Technical Lamp Data Tables	38
5.3.5	Operational Characteristics of Typical Light Sources	59
5.3.6	Colour and Colour Rendering	76
5.4	Illuminance and Luminance Surveys	79
5.4.1	Field Measurements	79
5.4.2	Electrical Lighting Surveys for Indoor Applications	80
5.4.3	Electrical Lighting Surveys for Exterior Applications	98
5.5	Reflectance and Transmittance Surveys	102

5.6	Luminaire Environmental and Operational Surveys	109
5.7	VDT Environmental Survey	116
5.8	Daylighting Survey	118
5.9	Visual Task Survey	143
5.10	Emergency Lighting Survey	146
5.11	Exit Lighting Survey	148
5.12	Lighting Energy Management Survey	151
5.13	Lighting Maintenance Surveys	176
5.14	Energy Audit	190
5.15	Photometric Reports, Laboratory Listing	192
5.16	Computer and Modeling Studies	195
5.17	Building Performance Evaluation Document List	198

LIST OF FIGURES

5.2.1	Weighting Factors to be Considered in Selecting Specific Illuminance within Ranges of Values for Each Category	33
5.3.1	Preferred Wall Luminances	35
5.3.2	Preferred Ceiling Luminances	35
5.3.3	Recommended Range of Wall Reflectance	37
5.3.4	Technical Data: General Service Lamps for 115–, 120–, and 125–Volt Circuits	38
5.3.5	Technical Data: Rough Service Lamps for 115–, 120–, and 130–Volt Circuits	40
5.3.6	Technical Data: Extended Service Incandescent Lamps	41
5.3.7	Technical Data: Vibration Service Lamps for 120– and 130–Volt Circuits	42
5.3.8	Technical Data: Tungsten–Halogen Lamps for General Lighting	43
5.3.9	Technical Data: Reflectorization R, ER and PAR Lamps for 120–Volt Circuits	45
5.3.10	Technical Data: Energy Saving Fluorescent Lamps	48
5.3.11	Technical Data: Hot Cathode Fluorescent Lamps (Rapid Starting) a	49
5.3.12	Technical Data: Compact Fluorescent Lamps	53
5.3.13	Technical Data: Cold Cathode Fluorescent Lamps	54
5.3.14	Technical Data: Typical Hot Cathode Fluorescent Lamps (Preheat Start)	55
5.3.15	Technical Data: Fluorescent Lamp Power Requirements	57
5.3.16	Operating Characteristics of Typical Incandescent Lamps	59
5.3.17	Operating Characteristics of Typical Tungsten–Halogen Lamps	60
5.3.18	Operating Characteristics of Typical Fluorescent Lamps	62
5.3.19	Operating Characteristics of Typical Mercury Lamps	65
5.3.20	Operating Characteristics of Typical Metal–Halide Lamps	69
5.3.21	Operating Characteristics of Typical High Pressure Sodium Lamps	71
5.3.22	Miscellaneous Data for Hid Lamps	73
5.3.23	Operating Characteristics of Typical Low Pressure Sodium Lamps	75
5.3.24	Comparison of Interreflection Efficiencies of Colored & Neutral Surfaces Having the Same Luminous Reflectance	76
5.4.1	Measuring Points for Stage I Task Illuminance Survey	81
5.4.2	Measuring Points for Stage II and III Task Illuminance Survey	92
5.4.3	Parking Facilities Surveying Grid	101
5.5.1	Reflectance Measurement	102

5.8.1	Determining Direct Beam Daylighting Penetration using Sunpath Diagrams for a Location of 50° N Latitude for Stage I & II	122
5.8.2	Determining Daylight Zones for Stage I & II	123
5.8.3	Vertical Angle θ	124
5.8.4	No Sky Point	124
5.8.5	Daylight Factor Survey Grid	126
5.8.6	Sunpath Diagram: 40° North Latitude	139
5.8.7	Sunpath Diagram: 44° North Latitude	140
5.8.8	Sunpath Diagram: 48° North Latitude	141
5.8.9	Sunpath Diagram: 52° North Latitude	142
5.11.1	FCC Approved Exit Signs	149
5.11.2	NBC Approved Exit Signs	149
5.11.3	NMS Approved Exit Signs	150
5.12.1	Example Building: Lighting Power Budget Calculation	171
5.13.1	Typical Light Loss Values for a Fluorescent Light System	178

LIST OF TABLES

5.2.1	Illuminance Categories and Illuminance Values for Generic Types of Activities in Interiors	31
5.2.2	Illuminance Categories for Commercial, Institutional, Residential and Public Assembly Interiors	32
5.3.1	Recommended Luminance Ratios	34
5.3.2	Recommended Ambient Luminances	34
5.3.3	Maximum Luminaire Luminances	34
5.3.4	Recommended Illuminance Ratios	36
5.3.5	Recommended Average Room Reflectance Values	36
5.3.6	Recommended Range of CRI	77
5.3.7	Colour and Colour Rendering Characteristics of Common Light Sources	78
5.4.1	Table for Stage I Task Illuminance Survey	81
5.4.2	Stage II, III Task Illuminance Survey	93
5.4.3	Ambient Luminance Measurements	94
5.4.4	Recommended Minimum Illumination Levels for Parking Areas	100
5.4.5	Recommended Minimum Illumination Levels for Pedestrian Ways	100
5.5.1	Recommended Average Room Reflectance Values	103
5.5.2	Glazing Dirt Maintenance Indices	105
5.5.3	Reflecting and Transmitting Materials	106
5.6.1	Properties of Finishes	113
5.6.2	Properties of Plastics Used in Lighting	114
5.8.1	Glazing Percentages Required for a 2% Average Daylighting Factor	119
5.8.2	Availability of Exterior Horizontal Illuminance for Selected Cities in Canada	119
5.8.3	Constant "a" for the Internally Reflected Component	127
5.8.4	Constant "v" for the Internally Reflected Component	127
5.8.5	Constant "e" for the Internally Reflected Component	128
5.8.6	Operating Ranges for Ambient Luminances	128
5.8.7	Maximum Luminance Values	129

5.9.1	Task Categories and Reference Illumination Levels	144
5.9.2	Adjustments to Reference Illuminances	145
5.12.1	Lighting Considerations and Ideas for Energy Management	153
5.12.2	Lighting Power Budget for Interior Common Areas	162
5.12.3	Lighting Power Budget for Exterior Areas	163
5.12.4	Workstation Area Allowance	163
5.13.1	Typical Failure Rates for F40 Fluorescent Lamps	179
5.13.2	Typical Ballast Failure Rate	179
5.13.3	Recommended Cleaning Agents for Lighting Maintenance	180
5.13.4	Trouble Shooting Lighting Systems	180

1. INTRODUCTION

1.1 PURPOSE AND OBJECTIVES

The primary purpose of this document is to present a methodology for assessing the illuminated environment as found in the interior and exterior of typical Crown office buildings.

Electric and daylighting are treated individually or together, according to the techniques and methodology available for their analysis.

This document can be used to assess the performance of lighting systems, daylighting included. It covers the quantity and quality issues that are considered important by applicable legislative authorities, building professionals and building users, and are part of the ergonomic issues of modern office spaces.

Three stages of diagnostics are used:

a) preliminary assessment;
b) simple measurement techniques;
c) specialized in-depth monitoring techniques.

These stages are explained in detail in this document and address issues related to both electric and daylighting.

1.2 BACKGROUND INFORMATION

Illumination systems are designed to provide adequate levels of lighting quantity and quality for the varied and dynamic nature of the many activities taking place in office environments.

The basis for lighting adequacy used in this document is derived from a body of world-wide scientific and practical knowledge. Although there are still many gaps in our knowledge of the human visual system, our ability to successfully light a space is reasonably good, provided that the physical and psychological needs of the occupant are properly addressed.

This entails preparing and delivering a proper lighting design, followed by a commissioning phase and a subsequent lighting maintenance program, designed to maintain the lighting system in good working conditions and designed to effectively adapt the lighting system to the changing dynamics of the office environment. Lighting design is a complex process, involving aesthetic and humanistic issues as well as technical issues, and is related to those disciplines which interact with or affect its installation, operation and performance. Also it involves economic and maintenance issues but, most importantly, involves the knowledge of the needs of the occupant and the ability to know how to best satisfy them. This document is unidisciplinary in nature and does not address the plurality of issues relating to luminous environments. It is the responsibility of the reader to seek a multi-disciplinary input, and not attempt to draw conclusions solely based on unidisciplinary perspectives. This multi-disciplinary input may be provided by other documents in the Series.

2. TERMS OF REFERENCE

2.1 GENERAL FRAMEWORK

The methodology presented in this document addresses two issues. The first, "**Quantity**", is concerned with assessing the contribution that electric lighting and daylighting make to the illumination level at workstations and support spaces within the building, and at specific outdoor locations. This provides the basis for testing compliance with the Canada Labour Code and other national or regional codes, and assessing the safety and the energy efficiency of working environments. The second, "**Quality**", is concerned with assessing the visual impact that quality lighting has on the environment of the office occupant.

The text deals with the analysis of a lighting system in three distinct stages:

Stage I, Preliminary Assessment, is concerned with the collection of data pertaining to the design, commissioning and operation of the building lighting systems, as well as with simple spot measurements and information collected during an expert walkthrough of the building. Some limited interviews with building occupants may also be included in this stage.

Stage II, Simple Measurement Techniques, is concerned with the in-depth surveying and measurement of basic illumination parameters, such as illuminance, luminance, reflectance, electrical and temperature parameters at specific locations as needed.

Stage III, Specialized In-Depth Monitoring, involves data collection and analysis requiring expert resources not normally available within regional jurisdiction, such as contrast, visual performance, spectral energy distribution, and elaborate daylighting surveys.

Reference material and detailed descriptions for field surveys and the use of analytical tools are in the Appendices.

2.2 LIMITATIONS OF EVALUATION TECHNIQUES

Although care is taken to ensure that the best available analytical tools are used to evaluate the visual environment, many gaps still exist in our knowledge of what constitutes the optimum quantity and quality of lighting to be delivered to a space, considering common visual ergonomic requirements, economic and physical constraints. The techniques presented here should enable the user to evaluate, with an acceptable degree of accuracy, the major characteristics of the visual environment and prevent, or help in correcting common problem areas. Developments occurring in visual research will lead to changes in some prescriptive requirements presented here.

This document introduces the following concepts and their limitations:

1. **Reflectance**, based on Lambertian distribution;
2. **Luminance range and luminance ratios**, based on empirical field studies of observer's reaction to varying degrees of luminance and luminance ratios. This will require further scientific studies before better recommendations can be implemented;

3. **Illuminance ranges**, based on the knowledge of the actual visual task characteristics, observer's physiological characteristics affecting his vision and impact of furniture type and layout;
4. **Relative Visual Performance**, based on recent and still ongoing work at NRC/IRC–OTTAWA and limited to monochromatic alphanumeric characters with no visible degradation of their legibility;
5. **Daylighting Factor**, based on **methodological** data available and accuracy of typical physical modeling and computer simulation techniques;
6. **Daylighting utilization**, based on common building construction technology and maintenance practices;
7. **Daylighting integration**, achieved through the use of truly proportional sensors and controls, sensitive to the luminous flux intensity available at the task.

Issues concerning the optimization of energy consumption and management, although important, are not treated in detail.

3. METHODOLOGY

3.1 STAGE I - PRELIMINARY ASSESSMENT

3.1.1 Description of Technique

This stage is concerned with providing a first-hand knowledge of the adequacy of lighting quantity, the identification of annoying glare sources, the proper utilization of available resources and the operation of control systems. Most of the buildings operational characteristics and actual or potential problems, can be identified in this stage.

The procedure has two components:

a) **an examination of drawings and archival records** (commissioning records included if available) and,
b) **a walkthrough of the building** to make field observations and simple spot measurements.

The sequence and weighting of these may differ according to circumstance.

3.1.2 Equipment/Material

Equipment and material needed to extract information from the drawings and from the walkthrough are:

- an architect's scale and annotated drawings;
- calculator;
- protractor and sun path diagrams;
- an illuminance/luminance meter (Litemete, spotmate 501 or equivalent);
- a calibrated reflectance chart;
- tape measure;
- polaroid instant camera;
- prepared observation forms;
- note pad;
- reference material (Labour Canada COSH Regulations, PWC Standards, IES Handbooks).

3.1.3 Detailed Procedures

3.1.3.1 Plan and Archive Review

Information is gathered prior to visiting the building site and consists of a collection of all those documents which are pertinent to the lighting system design, operation and maintenance. The following documents form the basis for this review:

1. Project Brief and Consultant Brief;
2. Architectural, Mechanical and Electrical "as-built" drawings and specifications;
3. tenant fit-up and layout drawings;

4. commissioning documentation (if available);
5. records of operation and occupancy schedules;
6. records of maintenance schedules;
7. records of tenants' complaints.

The review of these documents can provide the following information:

Project Brief and Consultant Brief

These documents are generally available for more recently built buildings.

The project brief describes the requirements of the client while the consultant brief describes the instructions to the consultant to design to those requirements. The following can be gathered:

1. description of planned client's activities within the building;
2. description of type and use of spaces required by clients with possible information on future requirements or changes;
3. specific functional requirements;
4. desirable features for both functional and aesthetic requirements;
5. population type and density, occupancy schedules and planned expansions if any;
6. description of hardware and software requirements;
7. description of building systems integration;
8. description of manual/automatic control, monitoring functions; and
9. description of daylighting requirements, if any.

Architectural, Mechanical and Electrical Drawings

Information gathered here is based on "as-built" drawings and can provide the following:

Architectural

1. building siting and orientation;
2. physical dimensions;
3. outside skyline obstructions (existing and planned), and their characteristics;
4. layout, orientation, dimensions and access to windows in work areas; and
5. fenestration geometry, glazing and shading devices;

Mechanical

6. mechanical ventilation systems, zoning and control;
7. HVAC system integration or dependence on daylighting or electric lighting energy output (this may not be obvious unless extracted from the original design team);

Electrical

8. electric and daylighting fittings;
9. light zones;
10. light sources;
11. electric and daylighting integration; and
12. lighting control schemes.

Tenant Fit-up and Layout Drawings

May provide:

1. furniture type and layout;
2. ceilings, walls, partitions and dividers, location, dimensions and reflectances;
3. floor type and reflectance;
4. window draping material, transmission and reflectance;
5. work areas identification and personalization; and
6. building services requirements and their functional and aesthetics characteristics.

Commissioning Documentation

It provides:

1. information on the operation and performance of lighting systems, indoor, outdoor and emergency;
2. information on manual and automatic lighting controls operation;
3. lighting zones operation and control characteristics; and
4. installation and operation of lamps, ballasts and other luminaire components.

Records of Operation and Maintenance Schedules of Lighting Systems

They are intimately related to each other and provide the following:

Operation

1. dynamic nature of the building operational requirements;
2. ability of lighting control system to cope with actual demand;
3. ability of the lighting system to adapt to changing requirements; and
4. lighting load and impact on the buildings energy profile.

Maintenance

May provide:

5. records of length and quality of operation for all building lighting systems and their controls;
6. rate of failure and location of lighting components;
7. useful data for the maintenance and enforcement of warranties; and
8. useful data for energy efficient retrofitting.

Records of Tenant's Complaints

Generally provided by the building manager.

They are very useful in providing the following:

1. information on the perceived adequacy of quantity and quality of lighting;
2. the adequacy of system response to occupant needs (i.e. type, level and location of controls);

3. the presence of annoying glare, deep shadows, light flickering and ballast noise;
4. the absence of, or desire for window access;
5. colour rendering problems;
6. thermal problems; and
7. others, such as infrared or ultraviolet degradation, and colour recognitions.

3.1.3.2 The Building Walkthrough

The building walkthrough provides a fast, logical, inexpensive and yet sensitive appraisal of the luminous environment and its interaction with other building systems. It not only verifies and refines observations made from the Plan and Archive Review, but also effectively targets more detailed investigative methods for further action. A walkthrough normally consists of a guided tour arranged through the PWC responsible property manager and involves visiting all areas of the building.

Care must be exercised to ensure that observations made take into consideration the dynamics of the building through daily and seasonal variations.

The objectives of the walkthrough are to obtain the following:

Daylighting issues

1. observation of existing conditions of work spaces and work surfaces;
2. identification of the actual function of, and adaptation to daylighting conditions;
3. assessment of daylight factor and daylight penetration into applicable areas of the building;
4. identification of situations where daylight has been successfully utilized or where it has contributed to problems in the visual field or otherwise;
5. brief spot measurements of luminance and illuminance for typical locations and for perceived problem areas;
6. observation of maintenance conditions related to daylight;
7. analysis of occupancy and use patterns to establish the range of visual tasks being performed and their location in relation to daylight sources;
8. assessment of user satisfaction with light conditions by reviewing any relevant survey material that has been collected. Where further surveys might be indicated, a checklist for questionnaire design will have to be considered;
9. identification of problem areas on building drawings noting the type of complaint if necessary;

Electric Lighting Issues

10. identification of the placement, zoning and switching of luminaires in relation to daylight sources (where applicable);
11. identification and classification of building uses from a visual requirement perspective;
12. identification of working areas of common visual requirements;
13. identification of switching arrangements and operation to meet local needs;
14. identification of problem areas due to unusual furniture type and layout, or tenants needs or lighting grid limitations;

15. illumination levels compliance with Labour Canada Regulations, PWC Office Lighting Standard and IESNA guidelines;
16. identification of luminance patterns which are too dark or too bright;
17. identification of very low or very bright reflective surfaces;
18. identification of any form of glare;
19. identification of energy waste through improper or insufficient control capabilities or the use of inefficient light sources;
20. identification of energy waste because of missmatch between lighting control zone and occupancy level;
21. identification of environmental complaints related to lighting either directly or indirectly (i.e. poor posture due to glare conditions).

Measurements Issues

They apply to the walkthrough exercise and generally consist of **spot measurement** for indoor/outdoor spaces to ascertain compliance with established standards, or of **area measurements** for spaces where the exact location of workstations is not known.

The range of measurements which can be undertaken is indicated below, while detailed descriptions are in the appendices.

Type of Measurement Required for Phase I

Description	Instrument	Appendix
Illuminance	Illuminance meter	5.4
Luminance	Luminance meter	5.4
Reflectance and Transmittance	Illuminance meter or reflectance charts	5.5
Average Daylighting Factor	Illuminance meter	5.8
VDT Contrast	Luminance meter	5.7
Electrical Parameters	Multi-meter	5.6, 5.12, 5.14

3.1.4 Assessment Procedures

3.1.4.1 Quantitative Assessment of Electric Lighting

- Combining the results of the Plan and Archive Review and of the Building Walkthrough can provide a preliminary measure of the light quantity.
- Illumination levels taken are checked for compliance with the Canada Labour Code Regulations, where applicable, and with PWC Standards, IESNA recommendations and Provincial Regulations as needed (see Appendix 5.2).
- The total connected lighting power load and annual light energy consumption are identified and checked for compliance with PWC Office Lighting Standard, publication ED16500 (see Appendices 5.2 and 5.14).

- The light control system performance is checked against the needs of the building occupants and deficiencies listed (see Appendix 5.12 and 5.14).
- The exit and emergency lighting is checked for compliance with Canada Labour Code Regulations and applicable Provincial Regulations, and deficiencies listed (see Appendices 5.2, 5.10 and 5.11).

3.1.4.2 Quantitative Assessment of Daylighting

- Combining the results of the Plan/Archive and Field Observations can provide a preliminary measure of the daylight effectiveness.
- Floor areas are identified as daylight zones on plan drawings by following procedures listed in Appendix 5.8 and checked during the building visit.
- Ratios of these zones to total useable floor area will indicate a rough proportion of lighting energy costs that could be saved through programmed switching of electrical lighting, not accounting for HVAC loading, hours of occupancy and qualitative aspects of daylighting. Where potential is evident further study may be warranted (Stage II and III Analysis).
- Daylight zones will also help to define those areas where access to a window or view may provide visual relief.
- Field observations can be used to summarize the suitability of existing workstation arrangements, partitions and finishes for better daylight utilization. Generally speaking, screens placed so that they are perpendicular to window walls and finished in matte, medium–light coloured materials are the most suitable for reflected glare control. In many cases glazed partitions may be appropriate. For VDT applications 1.0 m to 1.5 m high separating partitions may be suitable to eliminate veiling reflection glare while allowing for daylight penetration and easy visual contact with windows.
- The zoning and switching of luminaires will be briefly assessed at this point in relation to daylight to determine the adaptability of the building to programmed switching (see Appendix 5.8).

3.1.4.3 Qualitative Assessment of Electric Lighting and Daylighting

- Combining the results of the Plan and Archive Review and of the Building Walkthrough can provide a preliminary measure of the lighting quality.
- Luminance measurements, taken in the space with and without daylight, are checked against set guidelines for compliance (see Appendix 5.4 and 5.8).
- Sources of any type of glare are identified and comments on remedial action annotated on office plans (see Appendix 5.4 and 5.8).
- Luminous environments requiring special considerations are identified (i.e., VDT, drafting, laboratory work, mapping, etc.) and specific comments made. Utilize the Lighting Survey Form, Appendix 5.4 and identify the visual tasks requirements, using Appendix 5.7.
- Office partitions height and reflectance characteristics are checked for conformity to guidelines (see Appendix 5.3 and 5.5).
- Light switching arrangements are checked for suitability to the working environment they serve (see Appendix 5.8 and 5.12).
- Daylighting integration controls are checked for their true tracking ability of available light at task (see Appendix 5.8).

- Programmable lighting controls are checked for their ability to be quickly and inexpensively re-programmed to serve new needs, as well as their accessibility and ease of use and ability of load control without annoying or frustrating the user (see Appendix 5.12).
- Parking lot(s) and exterior grounds utilization pattern(s) are analyzed to determine if their light needs are addressed through proper illumination levels, glare control and lighting control (see Appendix 5.4 and 5.12).
- Daylight penetration, distribution, control and integration is analyzed to determine if the luminous environment is maintained within the prescribed levels set by client requirements (see Appendix 5.8).
- Possible glare problems at specific times during the year, caused by low sun angles conditions, are identified utilizing pertinent information, available from the local Atmospheric Environmental Services (see Appendix 5.8).
- Window management techniques and their use are identified and analyzed for their ability of easy glare control, good light distribution and ease of maintenance and information on equipment and surfaces finish maintenance practices is collected and analyzed for compliance with practices identified and agreed upon at the design stage.

3.1.5 Resource Allocation and Timing

The following is an estimation of time requirements for conducting a STAGE I investigation and is based on a building floor area of 10,000 m².

1. **Plan and Archive**: 4 person-days after receipt of all pertinent material;
2. **Walkthrough**: 8 person-days;
3. **Assessment Procedures**: 5 person-days, inclusive of report.

3.2 STAGE II - SIMPLE MEASUREMENT TECHNIQUES

3.2.1 Description of Technique

This stage is concerned with providing detailed information on lighting quantity and quality. The description of what elements are involved is as follows:

Lighting Quantity

- efficacy;
- illuminance levels;
- illuminance uniformity ratios;
- average daylight factor.

Lighting Quality

- reflectance and transmittance of surfaces;
- luminance of surfaces;
- luminance ratios;
- light source intensity;
- contrast;
- visual performance;

- lighting control strategies;
- lighting maintenance program;
- special areas: VDT workstations.

In addition, a **Building Energy Audit** should be carried out at this stage to identify the propriety of the connected load and its management efficiency.

3.2.2 Equipment/Material

Stage I may be consulted as needed. Additional equipment includes:

- calibrated reflectance chart;
- visual performance evaluator kit;
- walkie-talkie;
- second illuminance meter;
- temperature, voltage, current meters, electric multi-meters.

3.2.3 Detailed Procedures

3.2.3.1 Lighting Quantity: Efficacy

The efficacy of any lighting installation is determined by the ratio of the luminaire luminous output and the total power consumed by the luminaire (inclusive of control circuits and ballast losses).

Efficacy values are used to determine and compare the power "efficiency" of installed lighting systems. For this reason it is important to know that efficacy is dependent on the following:

- actual voltage delivered at the luminaire;
- voltage/current crest factor;
- ballast regulation characteristics;
- lamp's physical characteristics;
- environmental temperature;
- luminaire control mode.

Appendix 5.6 lists typical environmental and operational parameters, while Appendix 5.3 lists typical operating characteristics of various light sources.

3.2.3.2 Lighting Quantity: Illuminance Levels

Illuminance levels are normally surveyed to determine compliance with local, provincial or national regulations or codes.

The accuracy of the results is dependent on the following:

- type, precision, accuracy and calibration of instrument used as well as its environmental operating characteristics;
- operator's errors;
- thermally and electrically stable lighting system;
- number of points surveyed;
- methods of surveying;
- interference from extraneous luminous sources.

Appendix 5.4 deals with most of the above parameters.

3.2.3.3 Lighting Quantity: Illuminance Uniformity Ratios

They consist of average to minimum and maximum to minimum ratios and are used as guidelines to approximately express operational ranges of in-service illumination levels.

Appendix 5.3 describes them in detail.

3.2.3.4 Lighting Quantity: Average Daylighting Factor (ADF)

The ADF is the area-weighted average of all daylight factors (DF) of a space. ADF is used to relate the interior level of daylighting illumination as compared to its corresponding exterior level, under an unobstructed sky vault. With the exception of PWC*, the North American continent has not yet developed a comprehensive methodology for the use of ADF. However there is indication that the IESNA will introduce it in the near future.

Appendix 5.8 illustrates the practical survey of DF and ADF.

3.2.3.5 Lighting Quality: Reflectance and Transmittance

The reflectance and transmittance of materials are the most common means to control lighting quality and quantity (reflectance being the most used one). More specifically, reflectance is partly responsible for the amount and "quality" of light reflected from surfaces and, since this is the light seen by the eye, reflectance is partly responsible for the visual perception of the observer.

The simplification normally made for common office interiors is that all surfaces exhibit a Lambertian reflectance distribution which is typical of matte surfaces. This allows for the use of simple equations. Complex reflectance distributions will not be treated in this document and the reader is remanded to seek the professional help of expert advice (see listing of independent lighting laboratories, Appendix 5.15).

Reflectance surveys are done for all major surfaces which are part of the observer's visual field and also for task area surfaces. Transmittance surveys are generally limited to glazing window materials, window treatment materials and to lenses of luminaires.

Appendix 5.5 discusses the detailed procedures for field surveys and shows recommended values.

3.2.3.6 Lighting Quality: Luminance of Surfaces

Luminance of surfaces is largely responsible for the visual stimulus of the observer and as such imparts visual definition and character to both the task and its ambient.

Luminance surveys are done for typical workstations and their surrounding areas, as well as for common service spaces.

Their purpose is to identify if they are within the recommended range for a comfortable visual environment.

---

* PWC has developed a concept of a 2% ADF valid for areas not deeper than 6 m and occurring approximately at the room mid-point. Work is in progress to develop a daylighting design manual.

Appendix 5.4 describes the details and Appendix 5.3 shows recommended values.

3.2.3.7 Lighting Quality: Luminance Ratios

Luminance ratios are extracted from the data collected in the previous step and serve the purpose of ensuring luminous balances in the working environment.

See Appendices 5.3 and 5.4 for details and recommended ranges.

3.2.3.8 Lighting Quality: Light Source Intensity

This is defined as the luminous intensity in the direction of the viewer. The light source can be the sky as seen through a window, or it can be an electric luminaire visible to the eye of the observer, or it can be a bright patch of light, indirectly reflected by a ceiling, and visible to the observer's eye. These measurements are made to identify possible glare sources.

See Appendices 5.3 and 5.4 for instructions and recommended values.

3.2.3.9 Lighting Quality: Contrast

Contrast is one of the most important elements responsible for vision. Mathematically it is simply a ratio between the luminance of the target and the luminance of its background.

Contrast is one of the key elements for the determination of visual performance which is treated next.

3.2.3.10 Lighting Quality: Visual Performance

Visual performance can be defined as the speed and accuracy to perform visual tasks, or, in other words, the efficiency of performing visual tasks.

For our purposes visual performance is confined to reading alphanumeric visual displays of normal size character (6, 8 point). Visual performance is dependent from:

- the luminance of the visual task and its background;
- the contrast of the visual task;
- the size of the visual task;
- viewing time;
- the age of the observer;
- the visual acuity of the observer;
- the presence of veiling reflections;
- the posture of the observer.

It can be easily seen that all of the above issues constitute together a formidable barrier to interpreting successfully the results of a visual performance survey. Joint efforts between PWC and NRC has resulted in the availability of a simple visual performance evaluator kit, capable to analyse all of the above factors. The kit instructions will be available in 1988.

3.2.3.11 Lighting Quality: Lighting Control Strategies

Lighting controls are used for two basic functions: convenience and energy control.

It is therefore important to determine if any or both apply to specific areas of the building.

When convenience is the justification, then the basic light switch is the most common and economical device. When energy control is the justification, then a technical and economic analysis of the many switching systems available must be done.

The main criteria for this are as follows:

- control mode (i.e., full or low voltage, timer, photocell, infrared, etc.);
- control points (i.e., local, remote, telephone, etc.);
- function (i.e., on/off, multi-step and dimming, etc.);
- control zone (i.e., size controlled);
- flexibility (i.e., ease of adapting to changes);
- proprietary features (i.e., ability to accept and integrate components of different manufacturers);
- ease of use (i.e., limits on location, functions and accessibility);
- costs (i.e., for unit area or unit workstation);
- maintenance (i.e., recurring maintenance schedules requirements).

An analysis of these criteria will help in the determination of what control strategies work best for a specific building and, if integrated with an occupancy survey and an energy audit, will identify the impact on the operation of other building systems, such as the HVAC system and the electric system, together with the impact on energy and demand charges.

See Appendices 5.12 and 5.14 for specific field surveys information.

3.2.3.12 Lighting Quality: Lighting Maintenance Program

All lighting design techniques assume specific lighting maintenance practices and it is therefore very important to know in detail the extent to which these design objectives are actually met. Failure to know this will cause the lighting system to deliver unknown lighting levels, and probably with poor energy efficiencies, resulting in possible non-compliance with Labour Canada Regulations, in additional energy/demand charges and in voidance of components warranties.

All lighting maintenance programs have the following in common:

- selection and optimization of spot and or group relamping techniques;
- based on the above, selection and use of proper personnel and equipment;
- maintenance of required levels of quantity;
- identification and solution of problem areas;
- maintenance of components warranties;
- identification of end-of-use of equipment;
- identification of retrofitting opportunities;
- identification of changes required due to office reorganization.

Computerized lighting maintenance studies can be undertaken at low costs to ensure that most of the above concerns are addressed.

See Appendix 5.13 and 5.16 for more details.

3.2.3.13 Lighting Quality: VDT Areas

VDT workstations can be generally grouped as

i) interactive; or
ii) data entry.

For the first case, both illumination quantity and quality, are less critical than for the second case. This statement is based on the observation that operators of interactive VDT's do generally alternate machine work with traditional work, therefore providing for more opportunities of visual stress relief. In addition, many of these operators may actually not even use a reference document and rely almost entirely on screen supported information (i.e., programmers, designers, CAD and graphic operators, telephone operators, etc.).

Data entry operators do require a flexible lighting system, capable of providing the required range of dynamic illumination levels on a workstation principle working surfaces.

This can be achieved using general and task lighting, ceiling and/or furniture mounted (or located) lighting and utilizing multi–step lighting levels switches or continuous dimmers.

Data entry operators require that proper office ergonomic principles be used to layout and operate their workstations. IESNA is preparing a publication titled "Proposed Standard Practice for Lighting Offices Containing VDU's" (available in 1989). PWC is in process of preparing its own standard practice which will be available in 1989. Temporarily refer to Appendix 5.7.

3.2.3.14 Building Energy Audit

The building energy audit is aimed at the identification of deficiencies in the lighting systems, as they affect their ability to deliver the required quantity of illumination at a task in an efficient manner. It is important to realize that the energy performance of lighting systems is regulated by its maintenance practices. Poor maintenance is responsible for excessive drops in illumination levels, which tend to drive upward the demand for lighting energy. Very important also are the various occupancy patterns experienced throughout the year by the buildings, as they may very well indicate opportunities to recover wasted light energy.

Equally important is the realization that lighting energy is a significant component of the building heating load.

Most Canadian buildings are internally thermally dominated, thus indicating that the heating contribution of lighting loads to building heating is greater than its negative contribution to building cooling. An energy audit will strive to identify how to best integrate the heating contribution of the lighting into the buildings' HVAC system(s) and its impact on the maintenance of both systems. See Appendix 5.12 and 5.14 for details.

3.2.4 Assessment Procedures

3.2.4.1 Quantitative Assessment of Electric Lighting and Daylighting

Lighting quantity is assessed by examining and comparing measured values to reference values for items previously described in paragraph 3.2.1: Efficacy, Illuminance Levels, Illuminance Uniformity Ratios and Average Daylighting Factors (ADF). Illumination levels must satisfy the requirements of Labour Canada Regulations, PWC applicable standards and the recommendations of the IESNA (in this order).

Appendices 5.4, 5.6 and 5.8 detail the appropriate parameters.

3.2.4.2 Qualitative Assessment of Electric Lighting and Daylighting

Reference is made to the same items treated in paragraph 3.2.1 and related Appendices 5.4, 5.5, 5.7, 5.8, 5.10, 5.11, 5.12, 5.13, 5.16.

Qualitative values are for the most part based on expert consensus, and for these reasons target values suggested are not dogmatic, but serve the purpose of reducing our uncertainties, while we await for better solutions.

It must also be understood that it is impossible to fully and precisely define quality, as many of its finer points can only be appreciated by appealing to such intangibles as our inner sense of art, beauty, spatial definition, and physiological or psychological well being.

3.2.4.3 Building Energy Audit Assessment

The basic assessment tool is the electric utility bills used in conjunction with typical connected loads, energy and occupancy profiles for the building under examination. The utility bills can provide a monthly breakdown of energy and connected load charges. These are normalized to a typical year to ensure that unusual weather conditions do not bias the data collected. The normalized costs are then used to calculate the average connected and energy lighting loads, which are compared with typical buildings of known acceptable energy consumption profiles. Serious differences indicate significant connected and/or operational waste of the lighting systems. This will necessitate a detailed analysis of all individual lighting systems, their controls and the various office spaces occupancy patterns. This analysis can be greatly facilitated for those cases where dedicated lighting power supply is available. Recommendations are then prepared, aimed at optimizing the costs associated with operating an energy efficient light source, placed in an energy efficient luminaire, located correctly for the task and delivering the appropriate range of illumination and in use when the occupant is present and finally controlled in an effective manner.

It is possible to find on the market place computerized methods to quickly execute an energy audit. These are available from energy audit consultants. One which is commonly available and used by Federal agencies is the BESA program.

It is important to realize that accurate and reliable results, followed by sound action plans, can only be provided by specialists in this area.

Normally in–house expertise is limited to the identification of excessive energy loads and costs as they relate to lighting. Appendices 5.14 and 5.16 offer more details.

3.2.5 Resource Allocation and Timing

An approximate estimation is an allowance of 1 1/2 hours per workstation, utilizing a two–person team. This would include check measurements for VDT areas, support spaces and service areas. Aspects of lighting quantity external to targeted workstations can require 4 person–days, while similar issues relating to quality may require 6 person–days, using a reference floor area of 10,000 m^2.

3.3 STAGE III – SPECIALIZED IN–DEPTH MONITORING

3.3.1 Description of Technique

This stage is concerned with providing information on accurate occupancy patterns, accurate visual performance parameters, sophisticated luminance surveys, photometric testing and analysis of luminaires, complex surveys of VDT environments, complex daylighting surveys, daylighting evaluation by models, daylighting integration with other building systems, and pilot studies for new technologies or new ideas.

3.3.2 Equipment/Material

Stage I and II may be consulted as needed. Additional equipment includes visual performance instrumentation kit (available from PWC/Headquarters); an accurate luminance meter with various adapting lenses; an accurate daylighting factor meter (optional); access to scale modeling and appropriate illuminance/luminance photosensors, access to state–of–the–art software tools, capable to accurately simulate most luminous environments. Specialized occupancy analysis techniques are used for occupancy patterns evaluation.

3.3.3 Detailed Procedure

3.3.3.1 Accurate Occupancy Patterns

These are required to better fit lighting control strategies to the needs of the occupants, while reducing wasted energy for unoccupied spaces.

3.3.3.2 Visual Performance Parameters

At the moment we use a technique developed at NRC/IRC and valid for normal size printed alphanumeric material. This consists of utilizing a properly optically corrected special video camera to take pictures of the visual task. This information is digitized and entered into a computer program for data processing and analysis to derive a visual performance value which relates to the visual task at hand, its luminous environment and to the visual characteristics of the observer. Any other information based on luminance data can be extracted and manipulated at will quite easily.

The instrumentation package and associated instruction manual are currently available from PWC/Headquarters.

3.3.3.3 Sophisticated Luminance Surveys

They consist of luminance surveys, aimed at accurately mapping major working surfaces and their immediate environment with which they interact. Methods are explained in Appendix 5.4 and are valid for both electric and daylighting. However in the case of daylighting it is important to recognize that luminance surveys must be done under known stable sky conditions. Stable, uniform overcast skies or perfectly clear skies are the most desirable conditions. Luminance surveys should be done at night time to produce reference minimum level conditions, and at daytime to provide information on daylighting impact. The daytime surveys should be so selected as to represent worst case conditions with regards to average ambient levels of luminances, luminances ratios, minimum and maximum values. All surveys should be conducted for the relevant workers' position and covering an average visual angle of 120° wide by 60° high above a horizontal line. Polaroid photographs with acetate overlays can be effectively used to record any type of luminance survey, offering at the same time a clear, accurate and detailed record of space layout, treatment and utilization. This information often proves to be invaluable in the preparation of detailed analysis of environmental lighting performance and in providing supporting evidence to recommendations.

3.3.3.4 Complex Surveys of VDT Environments

This type of environment can generally fit two categories: Category 1 refers to work which is mostly VDT dependent (i.e., data entry operators, word processing, etc.). Category 2 refers to work which does not depend on a sustained use of VDT (i.e., conversational use, data retrieval, computational use, etc.).

VDT work is a highly visually demanding task and for this reason quality lighting requirements are generally more stringent, while lighting levels and controls are generally more flexible.

When dealing with type 2 category it is often possible to treat the space as an extension of the usual daily work. The major concerns are thus to limit excessive screen glare.

When dealing with type 1 category, the emphasis is placed not only on eliminating screen glare but also glare sources within the visual field altogether. In addition, screen display contrast and ambient maximum acceptable luminance ratios are investigated. See Appendix 5.7 for details.

Lighting controls for VDT applications should be within easy reach of the users, control a limited zone (i.e., a small cluster), allow for multi-level illumination and be easily adapted to office renovation requirements. Ergonomic studies considering the visual, aural, thermal, postural and space allocation environment can be conducted using as a general guideline the IESNA document titled "Proposed Standard Practices for Lighting Offices Containing VDU's" (available in 1989).

3.3.3.5 Long Term Complex Daylighting Surveys

These types of surveys are required when daylighting spatial distribution characteristics vary widely according to the use and organization of the office space. In this case it is difficult to predict, mathematically or otherwise, the luminous impact on the space and the recourse to long term monitoring is advisable. See Appendix 5.8 for specific details. When conducting these surveys it is important to ensure that measurements are taken

using consistent techniques which are not dependent on those factors which are to be measured. Accurate daylight distribution patterns, specialized infrared and ultraviolet surveys are part of this section but are done only when specifically requested or needed and are beyond the scope of this document.

3.3.3.6 Daylighting Evaluation by Models

Models can be physical or computerized. Physical modeling can be a way to accurately replicate and study the daylighting performance of a space under a variety of conditions, using either an artificial sky or a real one. Either way it is important to realize that experienced operators and data analyzers must be used to achieve meaningful results.

Computer simulation is available as a complement to the physical models or as a checker tool to evaluate multiple options during the design process. It is practically impossible to simulate all the complexities modeling can represent as it is practically impossible to model many design alternatives. Thus these two tools nicely complement each other. See Appendix 5.16 for more details.

3.3.3.7 Photometric Testing and Analysis

The analysis of lighting systems efficiency and optical performance may require that photometric testing be provided to ascertain differences between design and installed systems. In addition photometric testing may be done to check compliance for quality performance and technical specification requirements and other issues.

There are many companies offering photometric testing, complete with mechanical, electrical and heat transfer analysis.

Appendix 5.15 lists the most common of them and indicates available services and costs. The fundamental issue here to be understood is that photometric reports are based on specific reference conditions, which may or may not be realistic enough to supply accurate information.

Usually deviations from standard reference conditions can be accounted for by simple mathematical manipulation.

The testing laboratory should be advised of all typical working environment so that a proper analysis can be conducted. The following is a description of the major issues concerning this point.

- **Supply Voltage** – Average voltage, fluctuation and waveform as supplied to luminaires. Note that long feeders provide less voltage;
- **Temperature** – Ambient, plenum, ballast compartment and lamp surface temperature greatly affect luminaire light output and life performance;
- **Humidity** – When it is high it can affect the luminaire operation and performance;
- **Components** – Lamps and ballast, matching along with their switching control methods, determine if there is any incompatibility amongst them.

For field testing of environmental parameters see Appendix 5.6.

3.3.3.8 Pilot Studies

Pilot studies may be undertaken to test new devices, new systems or new hypothesis. When using new technology or attempting to alleviate field problems by implementing seemingly good solutions, which may not have a well proven tr ck record, it is essential that a well controlled pilot study be undertaken. This study usually includes properly worded questionnaires and in such cases refer to Document D23 – Questionnaires. Care must be exercised not only to ensure that the results obtained are valid for the entire project, but also that any impact on other building systems is taken into consideration.

In addition the user should be allowed not only to have a meaningful input, but also to comment on the acceptability of the solution(s) selected. An example may be the glare reduction of windows. Solutions may consist of the utilization of various types of venetian blinds, solar drapes, solar films, or drapes only, or a combination of the above. With the aid of the occupants, tests can be conducted to prove the acceptability of one or more solutions and then a best compromise reached as to the most acceptable solution from the technical, economic, energy performance, environmental, aesthetic and psychological perspective. The solution so selected is likely to be the most successful one and the benefits predicted to be the most accurate.

3.3.4 Assessment Procedure

3.3.4.1 Quantitative Assessment of Daylighting and Electric Lighting

They consist of:

1. the measurement survey and calculations leading to the average daylighting factors at prescribed checkpoints and for representative building areas (See Appendix 5.8);
2. the illuminance survey of daylit spaces for typical working conditions under overcast stable sky conditions with and without the operation of the electric lighting (See Appendix 5.4);
3. the implications on the energy use and mode of operation on building systems because of the introduction, use and integration of daylighting (See Appendix 5.12);
4. the determination of the energy profile and the optimization of the operation of all lighting systems to achieve best overall building energy performance (See Appendix 5.12 and 5.14).

3.3.4.2 Qualitative Assessment of Electric Lighting and Daylighting

They consist of:

1. the visual performance survey which can offer a clear picture of the potential and actual visual performance for each workstation tested.

   The data so collected is compared with the visual performance requirements table and deficiencies are listed. Each deficient situation is then individually analyzed in terms of repeating the visual performance survey but varying the

geometry of the workstation with respect to the lighting grid, or by improving the visual contrast or by increasing the task illuminance. Appropriate solutions considering human, technical and economic issues, are then formulated;

2. luminance surveys which can identify areas of excessive luminances or luminance ratios, therefore reducing or avoiding possible complaints (see Appendix 5.4);
3. specialized VDT surveys which are checked against recommendations for assessment of compliance with specifications (see Appendix 5.7);
4. reduced scale models which are constructed to study daylighting distribution and intensities throughout the year. Glare control mechanisms to limit excessive glare are also tested and selected according to technical, economic, ease of use and aesthetic issues (see Appendix 5.16);
5. the photometric and thermal testing of luminaires which lack good photometric data or which are used in an unusual manner or in an unusual environment. Their performance is then rated against specification requirements (see Appendix 5.15);
6. computer simulations for both electric and daylighting which are conducted to evaluate and rate lighting effectiveness at workstations and supporting spaces. Complex programs such as Lumen Micro, Superlite DOE2–1B and DOE2–IC, and Controlite (see Appendix 5.16) are used for this analysis.

3.3.5 Resource Allocation and Timing

There is no typical set approach and each case has to be investigated on its own merits.

4. REFERENCES

1. **Canada Occupational Safety and Health Regulations. Part VI. Levels of Lighting**. Canada Labour Code. Canada Gazette Part II. Vol. 120. No. 6. SQR/86-304. March. 1986. 18-21.

2. The Chartered Institute of Building Services. **CIBS Code for Interior Lighting.** London, 1984.

3. de Boer. J.B., and Fischer. D., **Interior Lighting.** Philips Technical Library. Second Edition.

4. Illuminating Engineering Society. **Daytime Lighting in Buildings.** Technical Report No. 4. Second Edition. London, 1972.

5. Kaufman. J. ed. **IESNA Reference Lighting Handbooks** Illumination Engineering Society - North America. 1984.

6. Kaufman. J. ed. **Lighting Handbook Applications**. New York: Illumination Engineering Society - North America. 1987.

7. Public Works Canada. **Office Lighting Standard. ED-16500**. 1986 AES/SAG 1-1:86-10. Ottawa.

8. DNNA. **Simulating Daylight with Architectural Models.** SCHILER. Merk editor, 1988.

9. M.S. Rea, F.R.S. Clark and M.J. Ouelette. **Photometric and Psychophysical Measurements of Exit Signs through Smoke.** National Research Council of Canada. NRC/DBR paper No. 1291. NRCC 24627 Ottawa, 1985.

5 APPENDICES

5.1 STANDARD TERMS AND UNITS OF MEASUREMENT

Adaptation The process by which the eye adapts itself to varying quantities of light or brightness.

Average Daylight Factor The ratio of the total daylight flux incident on the reference plane to the total area of the reference plane expressed as a percentage of the outdoor illuminance on a horizontal plane due to an unobstructed hemisphere of sky of an assumed or known luminance distribution.

Ballast Electrical device used to limit flow of electricity through a fluorescent or HID lamp. Ballasts are essential for the starting and operation of these types of lamps.

Brightness (subjective) The subjective attribute of any light sensation which elicits luminous magnitude such as being bright, light, dim or dark.

ESI. lx The level of sphere illumination which would produce task visibility equivalent to that produced by a specific lighting environment. This concept is now in disuse because of its inability to represent correctly the requirements of the visual system.

Colour Rendering General expression for the effect of a light source on the colour appearance of objects in conscious or subconscious comparison with their colour appearance under a reference light source.

Colour Rendering Index (of a Light Source) (CRI) Measure of the degree of colour shift objects undergo when illuminated by the light source as compared with the colour of those same objects when illuminated by a reference source of comparable colour temperature.

Colour Temperature of a Light Source The absolute temperature of a blackbody radiator having a chromaticity equal to that of the light source.

Daylight Factor The ratio of illumination on a horizontal interior surface (usually at workplane height) to exterior "available" illumination on a horizontal surface. This is taken in terms of a diffuse sky condition. Direct sun is excluded.

General Lighting Lighting systems which provide a general level of illumination throughout an area are referred to as general lighting systems.

Glare Light or brightness in the field of view which causes visual discomfort and/or interferes with seeing. It may be further categorized as:

discomfort glare – glare producing discomfort. It does not necessarily interfere with visual performance or visibility and as

disability glare – glare resulting in reduced visual performance and visibility. It often is accompanied by discomfort.

Illuminance, Ix The density of the luminous flux incident on a surface, it is the gradient of the luminous flux by the area of the surface, when the latter is uniformly illuminated.

Lamp A generic term for a man-made source of light. By extension, the term is also used to denote sources that radiate in regions of the spectrum adjacent to the visible.

Light Radiant energy that is capable of exciting the retina and producing a visual sensation. The visible portion of the electromagnetic spectrum extends from about 380 to 770 nm.

Light Adaptation The process by which the retina becomes adapted to a luminance greater than about 3.4 candelas per square metre (1 footlambert).

Light Loss Factor, LLF A factor used in calculating illuminance after a given period of time and under given conditions. It takes into account temperature and voltage variations, dirt accumulation on luminaire and room surfaces, lamp depreciation, maintenance procedures and atmosphere conditions. Formerly called maintenance factor.

Luminaire A complete lighting unit consisting of a lamp or lamps together with the parts designed to distribute the light, to position and protect the lamps and to connect the lamps to the power supply.

Luminaire Efficiency The ratio of luminous flux (lumens) emitted by a luminaire to that emitted by the lamp or lamps used therein.

Lumen The lumen is the quantitative unit for measuring light output from a light source (lamp). The total light output from a lamp is usually measured in lumens.

Luminance, L The physical measure of the stimulus which produces the sensation of luminosity (brightness) in terms of the intensity of the light emitted in a given direction (usually towards the observer) by unit area of a self-luminous or transmitting or reflecting surface. It is measured by the luminous intensity of the light emitted or reflected in a given direction from a surface element, divided by the area of the element in the same direction. The SI unit is the candela per square metre.

Luminance Contrast Is the relationship between the luminance of an object and its immediate background.

$$c = \left| \frac{Lb - Lo}{Lb} \right|$$

Lb = luminance of background
Lo = luminance of object

Luminous Efficacy of a Source of Light The quotient of the total luminous flux emitted by the total lamp power input. It is expressed in lumens per watt.

Note: The term luminous efficiency has in the past been extensively used for this concept.

Maintenance Factor, MF See light loss factor.

Reflectance The reflectance of a surface of a material or finish is the ratio of the light reflected from the surface to the amount falling on the surface. Usually stated as a percentage. Less light is reflected from a dark surface than a light one. Therefore, the dark surface has a lower reflectance (or reflection factor).

Reflected Glare Reflected glare is caused by the mirror image of a light source reflected from a high gloss surface or glass-covered surface. (i.e., the image of light source such as a window or fluorescent fixture on the screen of a VDT display.) See veiling reflections.

Supplementary Lighting Sometimes referred to as local lighting is a lighting system providing lighting over a relatively small area where the specific task is being performed. The illumination may be from a luminaire mounted near the task, or mounted on the equipment, or from remote spotlights. It is an economical way of providing higher illumination levels on a difficult seeing task. Supplementary lighting must be used in conjunction with a general lighting system.

Task Area The location where a visual task is being performed (the area on a desk). It is usually part of a workstation although there may be several related tasks being performed by a worker resulting in his using the whole workstation area. Task lighting would then be required for the workstation area.

Task Lighting Consists of a functional arrangement of luminaires with respect to the work area where the visual task is being performed. It is designed to provide illumination on the specific task being performed. In the context of this standard luminaires for task lighting are mounted on or recessed in the ceiling.

Uniformity Ratio The Ratio of the average illuminance to the minimum illuminance. The ratio usually applies to the values on the working plane and over the working area.

Veiling Reflection Regular reflections superimposed upon diffuse reflections from an object that partially or totally obscure the details to be seen by reducing the contrast. This sometimes is called reflected glare.

Visibility The quality or state of being perceivable by the eye. In many outdoor applications, visibility is defined in terms of the distance at which an object can be just perceived by the eye. In indoor applications it usually is defined in terms of the contrast or size of a standard test object, observed under standardized view-conditions, having the same threshold as the given object.

Visual Comfort Probability, VCP The rating of a lighting system expressed as a per cent of people who, when viewing from a special location and in a specified direction, will be expected to find it acceptable in terms of discomfort glare. Visual comfort probability is related to discomfort glare rating (DGR).

Visual Performance The quantitative assessment of the speed and accuracy required to perform a visual task.

VDT Visual Display Terminal, or cathode ray tube.

Visual Task Conventionally designates those details and objects that must be seen for the performance of a given activity, and includes the immediate background of the details or objects.

Note: The term visual task as used is a misnomer because it refers to the visual display itself and not the task of extracting information from it. The task of extracting information also has to be differentiated from the overall task performed by the observer.

Working Plane The horizontal, vertical or inclined plane in which the visual task lies, unless otherwise indicated the plane may be assumed to be horizontal and 0.76 m above the floor.

Workstation The part of usable area which is assigned to an office user for his or her individual job activities. Functional space and access space within the workstation make up the office user workstation.

5.2 GOVERNING AUTHORITIES, REGULATIONS AND GUIDELINES

1. **Canada Occupational Safety and Health Regulations. Part VI. Levels of Lighting**. Canada Labour Code, Canada Gazette Part II, Vol. 120, No. 6. SQR/86-304, March, 1986. 18-21.

2. Kaufman, J. ed. **Lighting Handbook Applications**. New York: Illumination Engineering Society - North America. 1987.

3. National Research Council of Canada. Associate Committee on the National Fire Code. Part 6, Installation, Inspection, Testing, Maintenance and Operation of Fire Protection Equipment and, Part 7, Inspection, Testing, and Maintenance of Fire Emergency Systems in High Buildings in **National Fire Code of Canada 1985**. NRCC No. 23175. Ottawa.

4. Public Works Canada. **Office Lighting Standard. ED-16500**. 1986 AES/SAG 1-1:86-10. Ottawa.

5. IESNA. **Proposed Standard Practices for Lighting Offices Containing VDU's** (available in 1989).

6. Public Works Canada, **Daylight Survey Method**, prepared by Prof. D. Moizer. Contract No. OTT84-62721/1. March 1986.

EXTRACTED FROM:

19/3/86 Canada Gazette Part II, Vol. 120, No. 6

PART VI

LEVELS OF LIGHTING

Application

6.1 This Part does not apply to lighting in the underground workings of mines.

Measurement of Average Levels of Lighting

6.2 For the purposes of this Part, the average level of lighting in an area shall be determined by making four or more measurements at different places in the area,

(a) where work is performed at a level higher than the floor, at the level at which the work is performed, and

(b) in any other case, 1 m above the floor,

and dividing the aggregate of the results of the measurements by the number of the measurements.

Minimum Average Levels of Lighting

6.3 The average level of lighting for a type of work or area referred to in column I of an item of Schedule I to this Part shall be not less than the average level set out in column II of that item.

6.4 The average level of lighting in an area referred to in column I of an item of Schedule II to this Part shall be not less than the average level set out in column II of that item.

6.5 The average level of lighting in an area referred to in column I of an item of Schedule III to this Part shall be not less than the average level set out in column II of that item.

Emergency Lighting Systems

6.6 (1) Where a failure in the lighting system in an area through which an employee passes in carrying out procedures referred to in paragraph 17.5(2)(b) or evacuation procedures referred to in paragraph 17.4(2)(c) will cause the level of lighting to be reduced to less than 3 dalx, an emergency lighting system shall be installed in the area.

(2) The emergency lighting system installed in accordance with subsection (1) shall

(a) operate automatically in the event of a failure of the lighting system; and

(b) provide an average level of lighting of 3 dalx.

SCHEDULE II - Conc.

AVERAGE LEVELS OF LIGHTING IN INDUSTRIAL AREAS--

Item	Column I Type of Area	Column II Average Level in Daix
2.	LABORATORIES	
	(a) Areas in which instruments are read and where errors in such reading may be hazardous to the safety or health of an employee	80
	(b) Areas in which a dangerous substance is handled	70
	(c) Areas in which	
	(i) laboratory work requiring close and prolonged attention is performed	60
	(ii) other laboratory work is performed	30
3.	LOADING PLATFORMS, STORAGE ROOMS AND WAREHOUSES	
	(a) Areas in which packages are checked and sorted	15
	(b) Docks, piers and other locations where packages and containers are loaded and unloaded	10
	(c) Areas in which grain and granular material is unloaded in bulk	3
	(d) Areas in which goods are stored in bulk or where the goods in storage are all of one kind	3
	(e) Any other area	1
4.	MACHINE AND WOODWORKING SHOPS	
	(a) Areas in which medium or fine bench or machine work is performed	50
	(b) Areas in which rough bench or machine work is performed	30
	(c) Any other area	20
5.	MANUFACTURING AND PROCESSING AREAS	
	(a) Major control rooms with dial displays	80
	(b) Areas in which a dangerous substance is processed, manufactured or used	
	(i) in main work areas	50
	(ii) in surrounding areas	20
	(c) Areas in which substances that are not dangerous substances are processed, manufactured or used or where automatically controlled equipment is operating	
	(i) in main work areas	10
	(ii) in surrounding areas	5
6.	SERVICE SPACE	
	(a) Stairways and elevators that are	
	(i) used regularly by employees	10
	(ii) used irregularly by employees	5
	(b) Stairways that are used only in emergencies	3
	(c) Corridors and aisles that are used by pedestrians and mobile equipment	
	(i) at main intersections	10
	(ii) at other locations	5
	(d) Corridors and aisles that are used by mobile equipment only	5
	(e) Corridors and aisles that are used by pedestrians only and are	
	(i) used regularly	5
	(ii) used irregularly	3

CANADA LABOUR CODE REQUIREMENTS

19/3/86 Canada Gazette Part II, Vol. 120, No. 6

SCHEDULE III

(Section 6.5)

AVERAGE LEVELS OF LIGHTING - GENERAL AREAS

Item	Column I Area	Column II Average Level in Dalx
1.	BUILDING EXTERIORS	
	(a) Entrances and exits that are	
	(i) used regularly by employees	10
	(ii) used irregularly by employees	5
	(b) Pedestrian walkways	
	(i) at vehicular intersections	3
	(ii) at other locations	1
	(c) Areas used by pedestrians and mobile equipment in which there is	
	(i) a high or moderate level of activity	2
	(ii) a low level of activity	1
	(d) Storage areas in which there is	
	(i) a high or moderate level of activity	3
	(ii) a low level of activity	1
2.	FIRST AID ROOMS	
	(a) in treatment and examination areas	100
	(b) in other areas	50
3.	FOOD PREPARATIONS AREAS	50
4.	PERSONAL SERVICE ROOMS	20
5.	BOILER ROOMS	20
6.	ROOMS IN WHICH PRINCIPAL HEATING, VENTILATION OR AIR CONDITIONING EQUIPMENT IS INSTALLED	7
7.	EMERGENCY SHOWER FACILITIES AND EMERGENCY EQUIPMENT LOCATIONS	5

Illuminance Selection Criteria extracted from IESNA Lighting Handbook 1987, J.F. Kaufman Ed. Applications Volume.

Illuminance Selection Criteria

1. Basic Information

Basic information required is as follows:

1. the visual display (item to be seen);
2. the age of the observer;
3. the importance of speed and/or accuracy to see the visual display;
4. the reflectance of the visual display background.

2. Procedure

The following four (4) step procedure is required to establish the appropriate illuminance value for a given visual task, as listed in the IESNA Application Volume. New York 1987.

1. Step 1: Definition of Visual Task
Define the type of visual activity and the place on which it occurs (i.e., reading a text on a horizontal surface).

2. Step 2: Selection of Illuminance Category
Select the appropriate Illuminance Category from Table 5.2.1 (if specific tasks are unknown) or from Table 5.2.2 (if specific tasks are known).

3. Step 3: Determination of the Illuminance Range
Select the recommended range of illuminance by looking at Table 5.2.1 (e.g., Category D, 200–300–500 lux range). Note that of the Categories A to J listed, A to C refer to general interior spaces, D to F refer to task areas only and are typical of common office spaces, and G to I refer to unusually demanding visual tasks.

4. Step 4: Determination of the Illuminance Value
From the range of illuminance determined in Step 3 above, select an illuminance value based on the 4 factors identified in paragraph 1 and following the instructions below:

For Categories A to C
- estimate occupants' average age;
- estimate average room reflectances (see Appendix 5.5 for detailed description of reflectance surveys);
- refer to Figure 5.2.1(a) extracted from IESNA Handbook and determine applicable weighting factors;
- add these factors and if total is –2, use the lowest illumination level of the selected range; if the total is +2 use the highest value; otherwise use the middle value.

For Categories D to I

- estimate occupants' average age;
- estimate importance of speed and accuracy;
- estimate average reflectance of task background;
- refer to Figure 5.2.1(b) and determine applicable weighting factors;
- add these factors and if total is −2, use the lowest illumination level of the selected range; if the total is +2 use the highest value; otherwise use the middle value.

Type of Activity	Illuminance Category	Ranges of Illuminances		Reference Work-Plane
		Lux	Footcandles	
Public spaces with dark surroundings	A	20-30-50	2-3-5	General lighting throughout spaces
Simple orientation for short temporary visits	B	50-75-100	5-7.5-10	
Working spaces where visual tasks are only occasionally performed	C	100-150-200	10-15-20	
Performance of visual tasks of high contrast or large size	D	200-300-500	20-30-50	
Performance of visual tasks of medium contrast or small size	E	500-750-1000	50-75-100	Illuminance on task
Performance of visual tasks of low contrast or very small size	F	1000-1500-2000	100-150-200	
Performance of visual tasks of low contrast and very small size over a prolonged period	G	2000-3000-5000	200-300-500	Illuminance on task, obtained by a combination of general and local (supplementary lighting)
Performance of very prolonged and exacting visual tasks	H	5000-7500-10000	500-750-1000	
Performance of very special visual tasks of extremely low contrast and small size	I	10000-15000-20000	1000-1500-2000	

Table 5.2.1 Illuminance Categories and Illuminance Values for Generic Types of Activities in Interiors. (Extracted from IES Application Volume, 1987 by permission from IESNA.)

Area/Activity	Illuminance Category
Air terminals (see Transportation terminals)	
Armories	C
Art galleries (see Museums)	
Auditoriums	
Assembly	C
Social activity	B
Banks (also see Reading)	
Lobby	
General	C
Writing Area	D
Tellers' stations	E
Barber shops and beauty parlors	E
Churches and synagogues	(see page 7-2)
Club and lodge rooms	
Lounge and reading	D
Conference rooms	
Conferring	D
Critical seeing (refer to individual task)	
Court rooms	
Seating area	C
Court activity area	E
Dance halls and discotheques	B
Nursing homes (see Health care facilities)	
Offices	
Accounting (see Reading)	
Conference areas (see Conference rooms)	
Drafting (see Drafting)	
General and private offices (see Reading)	
Libraries (see Libraries)	
Lobbies, lounges and reception areas	C
Mail sorting	E
Off-set printing and duplicating area	D
Post offices (see Offices)	
Reading	
Copied tasks	
Ditto copy	E
Micro-fiche reader	B
Mimeograph	D
Photographs, moderate detail	E
Thermal copy, poor copy	F
Xerograph	D
Xerography, 3rd generation and greater	E
Grooming	
Makeup and shaving	D
Full-length mirror	D
Handcrafts and hobbies	
Workbench hobbies	
Ordinary tasks	D
Difficult taks	E
Critical tasks	F
Easel hobbies	E
Ironing	D
Kitchen duties	
Kitchen counter	
Critical seeing	E
Noncritical	D
Kitchen range	
Difficult seeing	E
Noncritical	D
Kitchen sink	
Difficult seeing	E
Noncritical	D
Laundry	
Preparation and tubs	D
Washer and dryer	D

Table 5.2.2 **Illuminance Categories for Commercial, Institutional, Residential and Public Assembly Interiors.** (Partially extracted from IES Application Volume, 1987 by permission from IESNA.)

a. For Illuminance Categories A through C

Room and Occupant Characteristics	Weighting Factor		
	−1	0	+1
Occupants ages	Under 40	40–55	Over 55
Room surface reflectances*	Greater than 70 per cent	30 to 70 per cent	Less than 30 per cent

b. For Illuminance Categories D through I

Task and Worker Characteristics	Weighting Factor		
	−1	0	+1
Workers ages	Under 40	40–55	Over 55
Speed and/or accuracy**	Not important	Important	Critical
Reflectance of task background***	Greater than 70 per cent	30 to 70	Less than 30 per cent

* Average weighted surface reflectances, including wall, floor and ceiling reflectances, if they encompass a large portion of the task area or visual surround. For instance, in an elevator lobby, where the ceiling height is 7.6 metres (25 feet), neither the task nor the visual surround encompass the ceiling, so only the floor and wall reflectances would be considered.

** In determining whether speed and/or accuracy is not important, important or critical, the following questions need to be answered: What are the time limitations? How important is it to perform the task rapidly? Will errors produce an unsafe condition or product? Will errors reduce productivity and be costly? For example, in reading for leisure there are no time limitations and it is not important to read rapidly. Errors will not be costly and will not be related to safety. Thus, speed and/or accuracy is not important. If however, prescription notes are to be read by a pharmacist, accuracy is critical because errors could produce an unsafe condition and time is important for customer relations.

*** The task background is that portion of the task upon which the meaningful visual display is exhibited. For example, on this page the meaningful visual display includes each letter which combines with other letters to form words and phrases. The display medium, or task background, is the paper, which has a reflectance of approximately 85 per cent.

Figure 5.2.1 Weighting Factors to be Considered in Selecting Specific Illuminance Within Ranges of Values for Each Category. (Extracted from IES Application Volume, 1987 by permission from IESNA.)

5.3 REFERENCE LIGHTING TABLES

5.3.1 Introduction

Tables shown in this section are based on common international lighting practices and current technical specifications for luminaire performance.

5.3.2 Luminance Tables

Tables 5.3.1 to 5.3.3 represent recommendations to foster a balanced luminous environment and are based on expert consensus and not on scientific studies. Values contained herein should be used as guidelines only, and small deviations are quite acceptable.

Task to immediate surroundings	1 to 1/3
Task to remote dark surface	1 to 1/10
Task to remote light surface	1 to 10
Task to window or luminaire (if in field of view)	1 to 20
Anywhere in field of view	1 to 40

Table 5.3.1 Recommended Luminance Ratios

	Optimum Range	Minimum	Maximum
Walls	50 – 150 cd/m²		
Ceilings	100 – 300 cd/m²		
Task area and Surrounds	100 – 400 cd/m²		
Human Features	250 cd/m²	10 – 20 cd/m²	
Visible Sky	–	–	2000 cd/m²
Luminaires	1000 – 3500 cd/m²		7700 cd/m²

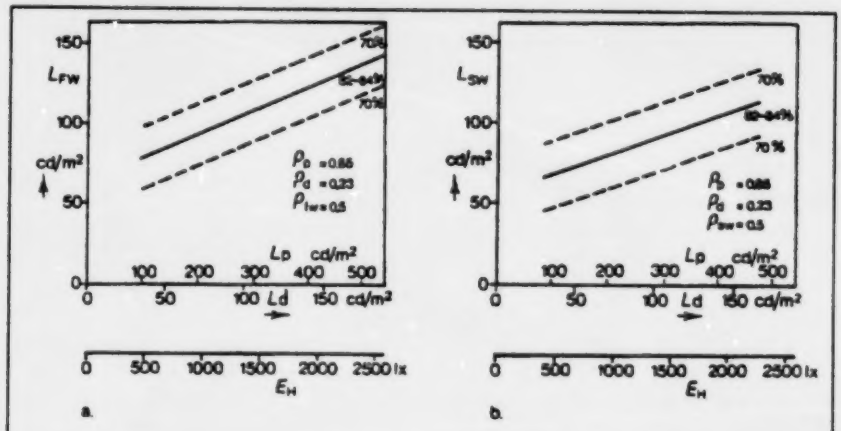
Table 5.3.2 Recommended Ambient Luminances

Angle Above Nadir (degrees)	Maximum Luminance (cd/m²)
45	7710
55	5500
65	3860
75	2520
85	1700

Note: 1. These values are maximum for both lengthwise and crosswise luminaire orientation

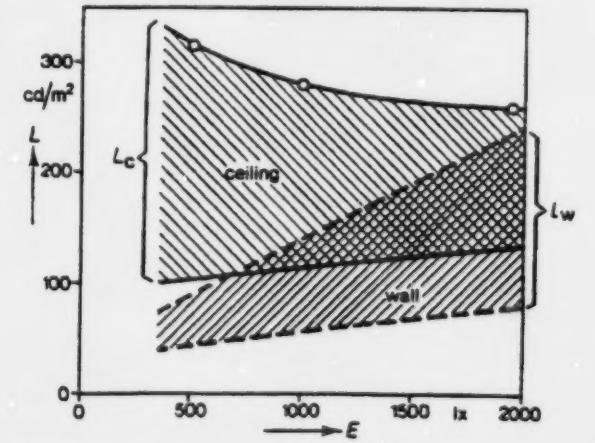
2. Luminaire luminance ratios of maximum to average is not to exceed 5:1 at angles of 45 to 85 degrees.

Table 5.3.3 Maximum Luminaire Luminances



(a) Preferred facing-wall luminance L_{FW} as a function of paper luminance L_p, desk-top luminance L_d and horizontal illuminance E_H; (b) Preferred side-wall luminance L_{SW} as a function of paper luminance L_p, desk-top luminance L_d and horizontal illuminance E_H. (Balder)

Figure 5.3.1 Preferred Wall Luminances



Range of preferred luminances for ceiling L_c and wall L_w as a function of illuminance E, on working plane. (D. Fisher)

Figure 5.3.2 Preferred Ceiling Luminances

The following ratios comply with IESNA and CIE recommendations:

Description	Ratio
Interior	
Task to immediate area	1 to 2/3
Task to support space	1 to 1/3
Minimum to average at task	0.8 to 1
Exterior: Parking	
Low/Medium activity	4 to 1 (average to minimum)
High activity	3 to 1 (average to minimum)
Pedestrian security	5 to 1 (average to minimum)
Driving lanes	4 to 1 (average to minimum) 40 to 1 (maximum to minimum)
Egress routes	3 to 1 (average to minimum) 10 to 1 (maximum to minimum)

Table 5.3.4 Recommended Illuminance Ratios

5.3.3 Room Finishes

The room surfaces' finishes are important factors in the determination of proper luminaire ranges and luminance ratios.

Table 5.3.5 shows recommended values.

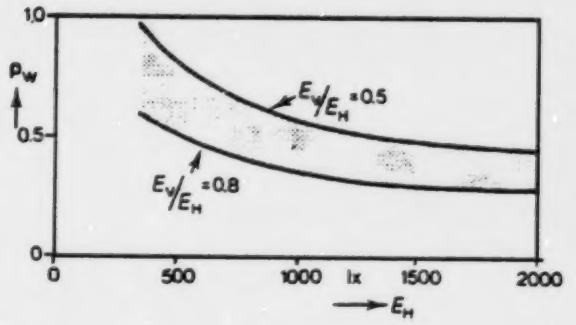
Higher and lower levels can be used provided that:

1. this level is selected for the purpose of improving the luminaire luminous flux distribution;

2. this level is selected for aesthetic reasons and does not exceed 10% of the occupant's field of vision, for this purpose defined as an on–axis horizontal angle of + 45 degrees and an on–axis vertical angle of + 45 degrees upper hemisphere and limited by the desk or other office furniture for the lower hemisphere.

Ceiling	80% +	*Maintain partition height to 1.2–1.5 m to help improve lighting distribution to enclosed space. Refer also to Document D08 Acoustic Environment Evaluation to define other desirable characteristics.
Walls	40 – 70%	
Partitions*	40 – 70%	
Floors	20 – 30%	
Furniture	25 – 45%	
Equipment	25 – 45%	
Drapes	40 – 60%	

Table 5.3.5 Recommended Average Room Reflectance Values



Recommended range of wall reflectance ρ_w as a function of horizontal illuminance E_h, with relative wall illuminance (E_v/E_H) as parameter. (D. Fisher)

Figure 5.3.3 Recommended Range of Wall Reflectance

5.3.4 Typical Technical Lamp Data Tables

Extracted from IES reference handbook 1984 and published by permission of IESNA.

Watts	Description	Base	Filament	Rated Average Life (h)	Approx. Initial Filament Temperature (k)	Maximum Bare Bulb Temperature* °C	Maximum Bare Bulb Temperature* °F	Base Temperature °C	Base Temperature °F	Approx. Initial Lumens	Rated Initial Lumens/ Watt ++	Lamp Depreciation ** (%)
300	S-14 inside frosted or clear	Med.	C-9	1500	2420	41	106	41	106	80	8.0	89
15	A-15 inside frosted	Med.	C-9	2500	-	-	-	-	-	126	8.4	83
25	A-19 inside frosted	Med.	C-9	2500	2550	43	110	42	108	230	9.2	79
34ab	A-19 inside frosted	Med.	CC-6 or CC-8	1500	-	-	-	-	-	410	12.1	
40	A-19 inside frosted and white#	Med.	C-9	1500	2650	127	260	105	221	455	11.4	87.5
50	A-19 inside frosted	Med.	CC-6	1000	-	-	-	-	-	680	13.6	-
52ac	A-19 inside frosted or clear	Med.	CC-8	1000	-	-	-	-	-	800	15.4	-
55a	A-19 clear or white	Med.	CC-8	1000	-	-	-	-	-	870	15.8	-
60	A-19 inside frosted and white#	Med.	CC-6	1000	2790	124	25	93	200	860	14.3	93
67ad	A-19 inside frosted or clear	Med.	CC-8	750	-	-	-	-	-	1130	16.9	-
70a	A-19 clear or white	Med.	CC-8	750	-	-	-	-	-	1190	17.0	-
75	A-19 inside frosted and white#	Med.	CC-6	750	2840	135	275	96	205	1180	15.7	92
90a	A-19 clear inside or frosted	Med.	CC-8	750	-	-	-	-	-	1620	18.0	-
95a	A-19 clear or white	Med.	CC-8	750	-	-	-	-	-	1710	18.0	-
100	A-19 inside frosted and white#	Med.	CC-8	750	2905	149	300	98	208	1740	17.4	90.5
100$	A-19 inside frosted and white	Med.	CC-8	1000	-	-	-	-	-	1680	16.8	-
100	A-21 inside frosted	Med.	CC-6	750	2880	127	260	90	194	1690	16.9	90
135a	A-21 clear or inside frosted	Med.	CC-8	750	-	-	-	-	-	2580	19.1	-
150	A-21 inside frosted	Med.	CC-8	750	2960	-	-	-	-	2880	19.2	89
150	A-21 white	Med.	CC-8	750	2930	-	-	-	-	2790	18.6	89
150	A-23 inside frosted or clear or white	Med.	CC-6	750	2925	138	280	99	210	2780	18.5	89
150	PS-25 clear or inside frosted	Med.	C-9	750	2910	143	290	99	210	2780	17.7	87.5
200	A-23 inside frosted white or clear	Med.	CC-8	750	2980	174	345	107	225	4000	20.0	89.5
200	PS-25 clear or inside frosted	Med.	CC-6	750	-	-	-	-	-	3800	19.0	-
200	PS-30 clear or inside frosted	Med.	C-9	750	2925	152	305	99	210	3700	18.5	85

Figure 5.3.4 Technical Data: General Service Lamps for 115-, 120-, and 125-Volt Circuits (Will Operate in Any Position but Lumen Maintenance is Best for 40 to 1500 Watts when Burned Vertically Base-Up)

Watts	Description	Base	Filament	Rated Average Life (h)	Approx. Initial Filament Temperature (k)	Maximum Bare Bulb Temperature*		Base-Temperature		Approx. Initial Lumens	Rated Initial Lumens/	Lamp Depreciation **
						°C	°F	°C	°F		Watt ++	(%)
300	PS-25 clear or inside frosted	Med.	CC-8	750	3015	205	401	112	234	6360	21.2	87.5
300	PS-25 clear or inside frosted	Med.	C-9	750	3000	135	275	79	175	6100	20.3	82.5
300	PS-25 clear or inside frosted	Mog.	CC-8	1000	-	-	-	-	-	5960	19.8	-
300	PS-25 clear or inside frosted	Mog.	C-9	1000	2980	166	330	102	215	5860	19.6	86
500	PS-35 clear or inside frosted	Mog.	CC-8	1000	3050	213	415	79	175	10600	21.2	89
500	PS-40 clear or inside frosted	Mog.	C-9	1000	2945	199	390	102	215	10140	20.3	-
750	PS-52 clear or inside frosted	Mog.	C-7A	1000	2990	-	-	-	-	15660	20.9	-
750	PS-52 clear or inside frosted	Mog.	CC-8 or 2CC-8	1000	3090	-	-	-	-	17000	22.6	89
1000	PS-52 clear or inside frosted	Mog.	C-7A	1000	2995	249	480	113	235	21800	21.8	-
1000	PS-52 clear or inside frosted	Mog.	CC-8 or 2CC-8	1000	3100	-	-	-	-	23600	23.6	89
1500	PS-52 clear or inside frosted	Mog.	C-7A	1000	3095	266	510	129	265	34000	22.6	78

* Lamp burning base-up in ambient temperature of 25° C (77°F)
† At junction of base and bulb.
†† For 120-volt lamps.
$ Used mainly in Canada.
# Lumen and lumen per watt values for white lamps are generally lower than for inside frosted.
** Percent initial light output at 70% of rated life.

a. Reduce wattage, high efficiency, 120 and 130 volt.
b. Substitute for 40-watt lamp.
c. Substitute for 60-watt lamp.
d. Substitute for 75-watt lamp.

Figure 5.3.4 Technical Data: General Service Lamps for 115-, 120-, and 125-Volt Circuits (Will Operate in Any Position but Lumen Maintenance is Best for 40 to 1500 Watts when Burned Vertically Base-Up) (cont'd)

Watts	Description	Base	Filament	Rated Average Life (h)	Maximum Over All Length (mm)	Maximum Over All Length (in.)	Average Light Centre Length (mm)	Average Light Centre Length (in.)	Approx. Initial Lumens	Rated Initial Lumens/ Watt	Lamp Lumen Depreciation † (%)
25*	A-19 inside frosted	Med.	C-17	1000	100	3 15/16	64	2 1/2	230	9.2	-
50	A-19 inside frosted	Med.	C-22	1000	100	3 15/16	64	2 1/2	480	9.6	76
75*	A-21 inside frosted	Med.	C-22 or C-17	1000	113	4 7/16	73	2 7/8	750	10.0	-
100	A-21 inside frosted	Med.	C-17	1000	135	5 5/16	98	3 7/8	1250	12.5	79
150*	A-23 inside frosted	Med.	C-17	1000	154	6 1/16	111	4 3/8	2130	14.2	-
150	PS-25 inside frosted	Med.	C-17	1000	176	6 16/16	133	5 1/4	2130	14.2	80
200*	PS-30 inside frosted or clear	Med.	C-9	1000	205	8 1/16	152	6	3380	16.9	82.5
200*	A-23 inside frosted or clear	Med.	C-17	1000	154	6 1/16	111	4 3/8	3380	16.9	-

* 115-volt not available.
†† Percent initial light output as 70% of rated life.

Figure 5.3.5 Technical Data: Rough Service Lamps for 115, 120 and 130-Volt Circuits (May be Burned in any Position)

Watts	Description	Base	Filament	Maximum Over All Length (mm)	Maximum Over All Length (in.)	Average Light Centre Length (mm)	Average Light Centre Length (in.)	Approx. Initial Lumens	Rated Initial Lumens/ Watt	Lamp Lumen Depreciation + (%)
15	A-15 inside frosted	Med.	C-9	89	3 1/2	60	2 3/8	125	8.3	83
25	A-19 inside frosted	Med.	C-9	100	3 15/16	64	2 1/2	235	9.4	79
34#	A-19 inside frosted	Med.	CC-6 or CC-8	113	4 7/16	76	3	390	11.5	-
40	A-19 inside frosted	Med.	C-9	108	4 1/4	73	2 7/8	420	10.5	87.5
52#	A-19 inside frosted	Med.	CC-8	113	4 7/16	79	3 1/8	740	14.2	-
60	A-19 inside frosted	Med.	CC-6	113	4 7/16	79	3 1/8	775	12.9	91.5
67#	A-19 inside frosted	Med.	CC-8	113	4 7/16	79	3 1/8	950	14.2	-
90#	A-19 inside frosted	Med.	CC-8	113	4 7/16	79	3 1/8	1425	15.8	-
100	A-19 inside frosted	Med.	CC-8	113	4 7/16	79	3 1/8	1490	14.9	92.5
100	A-21 inside frosted	Med.	CC-6	135	5 5/16	98	3 7/8	1450	14.5	-
135#	A-19 inside frosted and clear	Med.	CC-8	137	5 3/8	102	4	2200	16.3	-
150	A-23 inside frosted and clear	Med.	CC-6	160	6 5/16	117	4 5/8	2350	15.7	89
150	PS-25 inside frosted and clear	Med.	C-9	176	6 15/16	133	5 1/4	2300	15.3	85.5
200	A-23 inside frosted and clear	Med.	CC-8	157	6 3/16	177	4 5/8	3410	17.0	87.5
200	A-25 inside frosted and clear	Med.	CC-6	176	6 15/16	133	5 1/4	3250	16.2	-
200	PS-25 inside frosted and clear	Med.	CC-6	176	6 15/16	133	5 1/4	3220	16.1	-
200	PS-30 inside frosted and clear	Med.	C-9	205	8 1/16	152	6	3260	16.3	81
300	PS-30 inside frosted and clear	Med.	C-9	205	8 1/16	152	6	5190	17.3	79
300	PS-30 inside frosted and clear	Mog.	C-9	238	9 3/8	178	7	5190	17.3	84
500	PS-40 inside frosted and clear	Mog.	C-9	248	9 3/4	178	7	9070	18.1	80
750	PS-52 clear	Mog.	C-7A	332	13 1/16	241	9 1/2	14200	18.9	83
1000	PS-52 clear	Mog.	C-7A	332	13 1/16	241	9 1/2	19800	19.8	78
1500	PS-52 clear	Mog.	C-7A	332	13 1/16	241	9 1/2	30000	20.0	-

For 230, 240 and 250 Volts

Watts	Description	Base	Filament	Maximum Over All Length (mm)	Maximum Over All Length (in.)	Average Light Centre Length (mm)	Average Light Centre Length (in.)	Approx. Initial Lumens	Rated Initial Lumens/ Watt	Lamp Lumen Depreciation + (%)
100	A-21 inside frosted and clear	Med.	C-7A or C-9	133	5 1/4	98	3 7/8	1070	10.7	-
150	PS-25 inside frosted and clear	Med.	C-7A or C-9	176	6 15/16	133	5 1/4	1840	12.3	-
200	PS-30 inside frosted and clear	Med.	C-7A or C-9	205	8 1/16	152	6	2590	13.0	-
300	PS-35 inside frosted and clear	Mog.	C-7A	238	9 3/8	178	7	4290	14.3	-
500	PS-40 inside frosted and clear	Mog.	C-7A	248	9 3/4	178	7	7930	15.9	-
750*	PS-52 clear	Mog.	C-7A	332	13 1/16	241	9 1/2	13600	18.2	-
1000*	PS-52 clear	Mog.	C-7A	332	13 1/16	241	9 1/2	18900	18.9	78
1500*	PS-52 clear	Mog.	C-7A	332	13 1/16	241	9 1/2	27000	18.0	-

* Life is 2000 hours.
\+ Lamps 3000-5000 hours rated life for 120, 125, and 130 volts also are available in some wattages.
\# Reduce wattage, high efficacy.

Figure 5.3.6 Technical Data: Extended Service (2500 Hours Rated Life) Incandescent Lamps.+

Watts	Description	Burning Position	Base	Filament	Rated Average life (hours)	Maximum Over All Length		Average Light Centre Length		Approx. Initial Lumens	Rated Initial Lumens/ Watt	Lamp Lumen Depreciation * (%)
						(mm)	(in.)	(mm)	(in.)			
25	A-19 inside frosted or clear	Any	Med.	C-9	1000	100	3 15/16	64	2 1/2	260	10.4	-
50	A-19 inside frosted or clear	Not horizontal	Med.	C-9	1000	100	3 15/16	64	2 1/2	550	11.0	72
75	A-21 inside frosted or clear	Not horizontal	Med.	C-9	1000	133	5 1/4	98	3 7/8	935	12.5	-
100	A-23 inside frosted or clear	Any	Med.	C-9	1000	151	5 15/16	113	4 7/16	1340	13.4	83
100	A-21 inside frosted or clear	Not horizontal	Med.	C-9	1000	135	5 5/16	98	3 7/8	1400	14.0	-
150	A-25 inside frosted or clear	Any	Med.	C-9	1000	176	6 15/16	133	5 1/4	2390	15.9	-

* Percent initial light output at 70% of rated life.

Figure 5.3.7 Technical Data: Vibration Service Lamps for 120- and 130-Volt Circuits

Watts	Volts	Bulb and Finish	Base *	Filament	Maximum Over All Length (mm)	Maximum Over All Length (in.)	Average Light Centre Length (mm)	Average Light Centre Length (in.)	Rated Average Life (hours)	Approx. Initial Lumens	Rated Initial Lumens/ Watt	Lamp Lumen Depreciation + (%)	Approximate Colour Temperature (K)
200	120	T-3 clear	RSC	CC-8	79	3 1/8	-	-	1500	3460	17.3	96	2900
300	120	T-3 clear	RSC	C-8	119	4 11/16	-	-	2000	5950	19.9	96	2950
300	120	T-3 frosted	RSC	CC-8	119	4 11/16	-	-	2000	5900	19.3	96	2950
300	120	T-3 clear	RSC	CC-8	79	3 1/8	-	-	2000	5650	18.5	-	2900
300	120	T-4 clear	RSC	CC-8	79	3 1/8	-	-	2000	5650	18.9	96	3000
300	130	T-4 clear	RSC	CC-8	79	3 1/8	-	-	2000	5650	18.9	-	3000
300	120	T-4 frosted	RSC	CC-8	79	3 1/8	-	-	2000	5300	17.7	-	3000
350	**	T-3 IR refl	RSC	C-8	119	4 11/16	-	-	2000	10000	28.6	95	-
400	**	T-3 clear	RSC	CC-8	119	4 11/16	-	-	2000	9000	22.5	-	-
400	120	T-4 clear	RSC	CC-8	79	3 1/8	-	-	2000	7750	19.4	96	2950
400	125	T-4 clear	RSC	CC-8	79	3 1/8	-	-	2000	7500	18.7	-	3000
400	130	T-4 clear	RSC	CC-8	79	3 1/8	-	-	2000	7800	19.5	-	3000
500	120	T-3 clear	RSC	C-8$	119	4 11/16	-	-	1500	10500	20.8	96	-
500	120	T-3 clear	RSC	C-8	119	4 11/16	-	-	2000	10950	21.9	96	3000
500	120	T-3 frosted	RSC	C-8	119	4 11/16	-	-	2000	10700	21.4	96	3000
500	125	T-3 clear	RSC	C-8	119	4 11/16	-	-	2000	10500	21.0	-	3000
500	130	T-3 clear	RSC	C-8	119	4 11/16	-	-	2000	10750	21.5	96	3000
900	***	T-3 IR refl	RSC	C-8	256	10 1/16	-	-	2000	32000	35.6	95	-
900	277	T-3 IR refl	RSC	C-8	256	10 1/16	-	-	2000	31000	34.4	95	-
1000	120	T-6 clear	RSC or (Rect)	CC-8	143	5 5/8	-	-	2000	23400	23.4	96	3000
1000	120	T-6 clear	RSC or (Rect)	CC-8	143	5 5/8	-	-	4000	19800	19.8	93	2950
1000	120	T-6 frosted	RSC or (Rect)	CC-8	143	5 5/8	-	-	2000	22700	22.7	96	3000
1000	120	T-6 clear	RSC or (Rect)	CC-8	143	5 5/8	-	-	500	24500	24.5	-	3100
1000	220	T-3 clear	RSC	C-8	256	10 1/16	-	-	2000	21400	21.4	96	3000
1000	240	T-3 clear	RSC	C-8	256	10 1/16	-	-	2000	21400	21.4	96	3000
1000	***	T-3 clear	RSC	C-8	256	10 1/16	-	-	2000	29000	24.2	-	-
1250	208	T-3 clear	RSC	C-8	256	10 1/16	-	-	2000	28000	22.4	96	-
1500	208	T-3 clear	RSC	C-8	256	10 1/16	-	-	2000	35800	23.0	96	3050
1500	220	T-3 clear	RSC	C-8	256	10 1/16	-	-	2000	35800	23.2	96	3050
1500	240	T-3 clear	RSC	C-8	256	10 1/16	-	-	2000	35800	23.2	96	3050
1500	240	T-3 frosted	RSC	C-8	256	10 1/16	-	-	2000	32000	21.3	-	3050
1500	277	T-3 clear	RSC	C-8	256	10 1/16	-	-	2000	33700	22.5	96	3050
1500	277	T-3 frosted	RSC	C-8	256	10 1/16	-	-	2000	31600	21.0	-	3050
Single-Ended Types													
5	12	T-3 clear	G4	C-6	31	1 7/32	-	-	2000	60	12	-	3000
10	6	T-3 clear	G4	C-6	31	1 7/32	-	-	2000	120	12	-	3000
10	12	T-3 clear	G4	C-6	31	1 7/32	-	-	2000	-	-	-	3000
20	++	T-3 clear	G4	C-6	31	1 7/32	-	-	2000	350	17.5	-	3000
50	12	T-4 clear	GY 6.35	C-6	44	1 23/32	-	-	2000	950	19	-	3000
50	24	T-4 clear	GY 6.35	C-6	44	1 23/32	-	-	2000	900	18	-	3000
75	28	T-3 clear	Min.	CC-6	60	2 3/8	30	1 3/16	2000	1400	21.4	-	3000
100	12	T-3.5 clear	Minican.		57	2 1/4	-	-	1000	2500	25.0	-	-

Figure 5.3.8 Technical Data: Tungsten-Halogen Lamps for General Lighting (Burning Position-Any Except as noted)

Watts	Volts	Bulb and Finish	Base *	Filament	Maximum Over All Length (mm)	Maximum Over All Length (in.)	Average Light Centre Length (mm)	Average Light Centre Length (in.)	Rated Average life (hours)	Approx. Initial Lumens	Rated Initial Lumens/ Watt	Lamp Lumen Depreciation + (%)	Approximate Colour Temperature (K)
100	12	T-4 clear	GY 6.35	C-6	44	1 23/32	-	-	2000	2500	25	-	3000
100	24	T-4 clear	GY 6.35	C-6	44	1 23/32	-	-	2000	2000	20	-	3000
100	120	T-4 clear	Minican.	-	70	2 3/4	-	-	1000	1800	18.0	-	-
100	120	T-4 frosted	Minican.	-	70	2 3/4	-	-	1000	1750	17.5	-	-
100	120	T-4 clear	D.C. Bay	-	62	2 7/16	-	-	1000	1800	18.0	-	-
100	120	T-4 frosted	D.C. Bay	-	62	2 7/16	-	-	1000	1750	17.5	-	-
150	120	T-4 clear	Minican.	CC-2V	70	2 3/4	-	-	1500	2900	19.3	-	3000
150	120	T-4 clear	D.C. Bay	CC-2V	62	2 7/16	-	-	1500	2900	19.3	-	3000
150	120	T-4 frosted	D.C. Bay	-	62	2 7/16	-	-	1000	2700	18.0	-	-
150	120	T-10 clear or frosted	Med. Bay	C-6	105	4 1/8	75	2 15/16	2000	2500	16.7	-	3000
150	120	T-5 clear or frosted	D.C. Bay	C-6	95	3 3/4	-	-	2000	2000	16.7	-	3000
250	120	T-10 clear or frosted	Med. Bay	C-6	105	4 1/8	75	2 15/16	2000	4200	16.8	-	3000
250	120	T-5 clear or frosted	D.C. Bay	C-6	95	3 3/4	-	-	2000	4200	16.8	-	3000
250	120	T-4 clear	Minican.	CC-8	79	3 1/8	41	1 5/8	2000	4850	19.4	96	2950
250	120	T-4 frosted	Minican.	CC-8	79	3 1/8	41	1 5/8	2000	4700	18.8	96	2950
250	120	T-4 clear	D.C. Bay	CC-8	71	2 13/16	38	1 1/2	2000	4850	19.4	-	2950
250	120	T-4 clear	D.C. Bay	CC-8	71	2 13/16	41	1 5/8	2000	4850	19.4	96	2950
250	120	T-4 frosted	D.C. Bay	CC-8	71	2 13/16	41	1 5/8	2000	4700	18.8	96	2950
250	130	T-4 clear	Minican.	CC-8	79	3 1/8	41	1 5/8	2000	4850	19.4	-	2950
400	120	T-4 frosted	Minican.	CC-8	92	3 5/8	51	2	2000	8550	21.4	96	3050
400	120	T-4 clear	Minican.	CC-8	92	3 5/8	51	2	2000	8800	22.0	96	3050
500	120	T-4 clear	Minican.	CC-8	95	3 3/4	51	2	2000	11500	23.0	-	3000
500	120	T-4 frosted	Minican.	CC-8	95	3 3/4	51	2	2000	10000	20.0	-	3000
500	120	T-4 frosted	D.C. Bay	CC-8	87	3 7/16	54	2 1/8	2000	10100	20.9	96	3000
500	120	T-4 clear	D.C. Bay	CC-8	87	3 7/17	54	2 1/8	2000	10450	23.0	-	3000
500	130	T-4 clear	Minican.	CC-8	95	3 3/4	51	2	2000	11500	23.0	-	3000
1000	120	T-24 clear	Med. Bipost	CC-8	233	9 1/2	102	4	3000	22400	22.4	93	3050

* RSC = recessed single contact. RSC (Rect) = Retangular recessed single contact.
** 120, 130 volts
*** 208, 220, 240 volts
+ Percent initial light output at 70% of rated life.
++ 12 and 24 volts
$ Lamp provides maximum filament straightness under severe operating conditions.

Figure 5.3.8 Technical Data: Tungsten-Halogen Lamps for General Lighting (Burning Position-Any Except as noted) (cont'd)

Watts	Bulb	Description	Base	Maximum Over All Length (mm)	Maximum Over All Length (in.)	Approx. Beam Spread (deg.)	Approx. Beam Lumens	Approx. Total Lumens	Approx. Average Candle-power **f	Rated Average Life (hours)
R Lamps for Spotlighting and Floodlighting (Parabolic Reflector)										
30	R-20	Flood	Med.	100	3 15/16	85	150	205	290	2000
50	R-20	Flood	Med.	100	3 15/16	90	430	435	550	2000
75	R-30	Spot	Med.	136	5 3/8	50	400	850	1730	2000
75	R-30	Flood	Med.	136	5 3/8	130	610	850	430	2000
150	R-40	Spot	Med.	165	6 1/2	37	835	1825	7000	2000
150	R-40	Flood	Med.	165	6 1/2	110	1550	1825	1200	2000
300	R-40	Spot	Med.	165	6 1/2	35	1800	3600	13500	2000
300	R-40	Flood	Med.	165	6 1/2	115	3000	3600	2500	2000
300	R-40a	Spot	Med.	173	6 7/8	35	1800	3600	13500	2000
300	R-40a	Flood	Med.	173	6 7/8	115	3000	3600	2500	2000
300	R-40a	Spot	Mog.	184	7 1/4	35	1800	3600	13500	2000
300	R-40a	Flood	Mog.	184	7 1/4	115	3000	3600	2500	2000
500	R-40a	Spot	Mog.	184	7 1/4	60	3300	6500	22000	2000
500	R-40a	Flood	Mog.	184	7 1/4	120	5700	6500	4750	2000
1000	R-60ag	Spot	Mog.	257	10 1/8	32	11500	18300	135000	3000
1000	R-60ag	Flood	Mog.	257	10 1/8	110	15500	18300	15500	3000
ER Lamps for Spotlighting and Floodlighting (Ellipsoidal Reflector)										
44	ER-30b	Light inside frost	Med.	162	6 3/8	--	--	420	440	5000
50	ER-30	Light inside frost	Med.	162	6 3/8	--	--	525	--	2000
67	ER-30b	Light inside frost	Med.	162	6 3/8	--	--	700	1030	5000
75	ER-40	Light inside frost	Med.	162	6 3/8	--	--	850	--	2000
90	ER-30b	Light inside frost	Med.	162	6 3/8	--	--	950	1450	5000
90	ER-40	----	Med.	187	7 3/8	--	--	--	1200	4000
120	ER-40	Light inside frost	Med.	187	7 3/8	--	--	1475	--	2000
135	ER-40	----	Med.	187	7 3/8	--	--	--	2050	4000
R Lamps for General Lighting d (Parabolic Reflector)										
500	R-52	Wide beam	Mog.	300	11 3/4	90	--	7750	--	2000
750	R-52	Wide beam	Mog.	300	11 3/4	110	--	13000	--	2000
1000	R-52a	Wide beam	Mog.	300	11 3/4	110	--	16300	--	2000
1000	RB-52	Wide beam	Mog.	322	12 11/16	130	--	18900	--	2000

Figure 5.3.9 Technical Data: Reflectorization R, ER and PAR Lamps for 120-Volt Circuits

Watts	Bulb	Description	Base	Maximum Over All Length (mm)	Maximum Over All Length (in.)	Approx. Beam Spread (deg.)	Approx. Beam Lumens	Approx. Total Lumens	Approx. Average Candle-power **f	Rated Average Life (hours)
PAR Lamps for Spotlighting and Floodlighting e (Parabolic Reflector)										
55*	PAR-38	Spot	Med. Skt.	135	5 5/16	30x30	--	520	--	2000
55*	PAR-38	Flood	Med. Skt.	135	5 5/16	60x60	--	520	--	2000
65*	PAR-38	Spot	Med. Skt.	135	5 5/16	30x30	--	--	5100	2000
65*	PAR-38	Flood	Med. Skt.	135	5 5/16	60x60	--	--	1850	2000
65*	PAR-38	Spot	Med. Skt. Prong	110	4 5/16	30x30	--	--	--	2000
65*	PAR-38	Flood	Med. Skt. Prong	110	4 5/16	60x60	--	--	--	2000
75	PAR-38	Spot	Med. Skt.	135	5 5/16	30x30	465	750	3800	2000
75	PAR-38	Flood	Med. Skt.	135	5 5/16	60x60	570	750	1500	2000
80*	PAR-38	Spot	Med. Skt.	135	5 5/16	--	--	--	--	2000
80*	PAR-38	Flood	Med. Skt.	135	5 5/16	--	--	--	--	2000
85*	PAR-38	Spot	Med. Skt.	135	5 5/16	30x30	--	--	--	2000
85*	PAR-38	Flood	Med. Skt.	135	5 5/16	60x60	--	--	--	2000
90*	PAR-38	Spot	Med. Skt.	135	5 5/16	--	--	--	--	2000
90*	PAR-38	Flood	Med. Skt.	135	5 5/16	--	--	--	--	2000
90g	PAR-38	Flood	Med. Skt.	135	5 5/16	30x30	735	1450	3580	2000
100	PAR-38	Spot	Med. Skt.	135	5 5/16	30x30	--	1250	--	2000
100	PAR-38	Flood	Med. Skt.	135	5 5/16	60x60	--	1250	--	2000
120*	PAR-38	Spot	Med. Skt.	135	5 5/16	30x30	--	1420	12000	2000
120*	PAR-38	Flood	Med. Skt.	135	5 5/16	60x60	--	1420	4250	2000
120*	PAR-38	Spot	Med. Side Prong	110	4 5/16	30x30	--	1420	--	2000
120*	PAR-38	Flood	Med. Side Prong	110	4 5/16	60x60	--	1420	--	2000
150	PAR-38i	Spot	Med. Skt.	135	5 5/16	30x30	1100	1735	11000	2000
150	PAR-38i	Flood	Med. Skt.	135	5 5/16	60x60	1350	1735	3700	2000
150	PAR-38	Spot	Med. Side Prong	110	4 5/16	30x30	1100	1735	11000	2000
150	PAR-38	Flood	Med. Side Prong	110	4 5/16	60x60	1350	1735	3700	2000
200	PAR-46	Narrow Spot	Med. Side Prong	102	4	17x23	1200	2325	32500h	2000
200	PAR-46	Med. Flood	Med. Side Prong	102	4	20x40	1300	2325	11200h	2000
250	PAR-38g	Spot	Med. Skt.	135	5 5/16	26x26	1600	3180	25000	4000
250	PAR-38g	Flood	Med. Skt.	135	5 5/16	60x60	2400	3180	6500	4000
300	PAR-56i	Narrow Spot	Mog. End Prong	127	5	15x20	1800	3750	70000h	2000
300	PAR-56i	Med. Flood	Mog. End Prong	127	5	20x35	2000	3750	24000h	2000
300	PAR-56i	Wide Flood	Mod. End Prong	127	5	30x60	2100	3750	10000h	2000

Figure 5.3.9 Technical Data: Reflectorization R, ER and PAR Lamps for 120-Volt Circuits (cont'd)

Watts	Bulb	Description	Base	Maximum Over All Length (mm)	Maximum Over All Length (in.)	Approx. Beam Spread (deg.)	Approx. Beam Lumens	Approx. Total Lumens	Approx. Average Candle-power **f	Rated Average Life (hours)
PAR Lamps for Spotlighting and Floodlighting e (Parabolic Reflector) (cont'd)										
500	PAR-64	Narrow Spot	çExtended 3/4	153	6	13x20	3000	6000	110000h	2000
500	PAR-64	Med. Flood	çMog. End3/4	153	6	20x35	3400	6000	35000h	2000
500	PAR-64	Wide Flood	çProng 3/4	153	6	35x60	3500	6000	12000h	2000
500	PAR-56g	Narrow Spot	Mog. End Prong	127	5	15x32	4900	7650	96000	4000
500	PAR-56g	Med. Flood	Mog. End Prong	127	5	20x42	5700	7650	43000	4000
500	PAR-56g	Wide Flood	Mog. End Prong	127	5	34x66	5725	7650	19000	4000
1000	PAR-64g	Narrow Spot	çExtended 3/4	153	6	14x31	8500	19400	180000	4000
1000	PAR-64g	Med. Flood	çMog. End3/4	153	6	22x45	10000	19400	80000	4000
1000	PAR-64g	Wide Flood	çProng 3/4	153	6	45x72	13500	19400	33000	4000

* High Efficacy, reduced wattage.
** In central 10° cone.
a Heat resistant glass bulb.
b Krypton filled.
c To 10% of maximum candlepower.
d Some of these types are also available for 230 to 260-volt circuits.
e All PAR lamps have bulbs of molded heat-resistant glass.
f Central cone defined as 5° cone for all spots and 10° cone for all floods.
g Halogen cycle lamps.
h Horizontal operation. May be slightly lower for vertical operation.
i Also available with an interference filter reflector.

Figure 5.3.9 Technical Data: Reflectorization R, ER and PAR Lamps for 120-Volt Circuits (cont'd)

	Rapid Start						Preheat Start		Instant Start		
Nominal length											
Millimetres	900	1200	2400	2400	2400	1200	1200	1500	1200	2400	2400
Inches	36	48	96	96	96	48	48	60	48	96	96
Bulb	T-12	T-12	T-12	T-12	PG-17	PG-17	T-12	T-17	T-12	T-8	T-12
	38-mm	38-mm	38-mm	38-mm	54-mm	54-mm	38-mm	54-mm	38-mm	25-mm	38-mm
Base	Med. Bipin	Med. Bipin	Recess DC	Recess DC	Recess DC	Recess DC	Med. Bipin	Mog. Bipin	Single Pin	Single Pin	Single Pin
Lamp Amperes	0.453	0.45	0.81	1.58	1.57	1.53	0.45				0.44
Approx. lamp volts	64	84	134	137	144	64	84				153
Approx. lamp watts a	25	34-35 d	95	185-195	185	95	34	82-84	30-32	40-41	60
Lamp watts replaced a	30	40	110	215	215	110	40	90	40	50	75
Rated life (hours) b	18000	20000	12000	10000-12000	12000	12000	15000	9000	9000	7500	12000
Initial lumens c											
Cool white	2000	2770	8300	13000	14000	6550	2800	6175	2550	3725	5500
Deluxe cool white		1925	6000								4000
Warm white	2050	2820	8500		13000		2900				5700
Deluxe warm white		1925	5720								3870
White		2820	8300					6400		3795	5600
Daylight		2300						5400			4800
Supermarket white		2050									4250
Royal white		2900	8800								5700
Lite-white		2925	8800	13800	14900				2700		5850
Lite white deluxe		2925		8800					2700		5850
Warm lite deluxe		2925		8800					2700		5850
Regal white		2450									5100
Super saver II		3050							2750		6000
3 K		2900	8800						2700		5800
Chroma 50											4100
Optima 50		2025									
Super white		2630									5220
Optima 32		2260									4200
Vita-lite		2010									4015
Ultralume 83		2920									5860
Ultralume 84		2980									5860
Ultralume 85		2980									5860
Colortone 50											4100
Design 50		2250									
SP 30		2900									5950
SP 35		2900	8550								5800
SP 41		2850	8600								5800

* The life and light output rating of fluorescent lamps are based on their use with ballasts that provide proper operating characteristics. Ballasts that do not provide proper electrical values may substantially reduce either lamp life or light output, or both.

a For rapid start lamps, includes watts for cathode heat.

b Rated life under specified life conditions with three hours per start. At longer burning intervals per start, longer life can be expected.

c At 100 hours. Where colour is made by more than one manufacturer, lumens and footlamberts represent average of manufacturers.

d Also in 32-watt cathode-cutout, but with reduced life.

Note: All electrical and lumen values apply only under standard photometric conditions.

Figure 5.3.10 Technical Data: Energy Saving Fluorescent Lamps*

	Circline				U-Shaped		Lightly Loaded Lamps						
Nominal length (millimetres)	165 dia	210 dia	300 dia	400 dia	600	600	900	1200	1200	1200	900	1200	1
(inches)	6.5 dia	8.25 dia	12 dia	16 dia	24	24	36	48	48	48	36	48	6
Bulb	T-9	T-9	T-10	T-12	T-12	T-12	T-12	T-12	T-12	T-10	T-8	T-8	
Base	4 Pin	4 Pin	4 Pin	4 Pin	Med. Bipin	Med. Bipin	Med. Bipin	Med. Bipin	Med. Bipin	Med. Bipin	Med. Bipin	Med. Bipin	Med. Bipin
Leg spacing					92 mm 3 5/8 in	152 mm 6 in.							
Approx. lamp current (amperes)	0.38	0.37	0.425	0.415	0.42	0.43	0.43	0.43	0.43	0.42	0.265	0.265	
Approx. lamp volts	48	61	81	108	103	100	81	101	101	104	100	135	
Approx. lamp watts f	20	22.5	33	41.5	41	40.5	32.4	41	41	41	25	32	40
Rated life (hours) b	12000	12000	12000	12000	12000	12000	18000	20000	15000	24000	20000	20000	20000
Lamp lumen depreciation (LLD) c		72	82	77	84	81	84						
Initial Lumens d													
Cool white	800	1065	1870	2580	2900	2935	2210	3150	3250	3200	k	k	k
Deluxe cool white		875	1425	2000	2020	2065	1555	2200		2270			
Warm white	825	1065	1835	2550	2850	2965	2235	3175	3250	3250			
Deluxe warm white	630	800	1375	1950	1980	2040	1505	2165					
White		1100	1870	2650	2850	2965	2255	3185	3250	3250			
Daylight		906	1550	2165			1900	2615	2650	2700			
Factors for calculating luminance e													
Candelas per square metre	11.5	8.4	4.6	3.3	2.65	2.65	3.58	2.65	2.65	3.18	5.42	4.03	3
Candelas per square foot	1.07	0.78	0.43	0.31	0.25	0.25	0.33	0.25	0.25	0.30	0.50	0.37	0.30

Figure 5.3.11 Technical Data: Typical Hot-Cathode Fluorescent Lamps (Rapid Starting) a

	Medium Loaded Lamps									
Nominal length (millimetres)	600	750	900	1050	1200	1500	1600	1800	2100	2400
(inches)	24	30	36	42	48	60	64	72	84	96
Bulb	T-12	T-12	T-12	T-12	T-12	T-12	T-12	T-12	T-12	T-12
Base	Recess DC	Recess DC	Recess DC	Recess DC	Recess DC	Recess DC	Recess DC	Recess DC	Recess DC	Recess DC
Approx. lamp current (amperes)	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.79
Approx. lamp volts	41		59		78	98		117	135	153
Approx. lamp watts f	37		50		63	75.5		87	100	113
Rated life (hours) b	9000	9000	9000	9000	12000	12000	12000	12000	12000	12000
Lamp lumen depreciation (LLD) c	77		77	77	82	82	82	82	82	82
Initial lumens d										
Cool white	1700	2290	2885	3516	4300	5400	5800	6650	7800	9150
Deluxe cool white					3050			4550		6533
Warm white	1700				4300	5500		6500		9200
Deluxe warm white										6475
White								6475		9200
Daylight	1400		2476	3100	4300	4650	4900	5600	6867	7800
Factors for calculating luminance e										
Candelas per square metre	5.54	4.35	3.58	3.04	2.65	2.1	1.95	1.7	1.44	1.24
Candelas per square foot	0.51	0.40	0.33	0.28	0.25	0.20	0.18	0.16	0.13	0.12
	Highly Loaded Lamps									
Nominal length (millimetres)	1200	1800	2400	1200	1500	1800	2400	1200	1800	2400
(inches)	48	72	96	48	60	72	96	48	72	96
Bulb	T-10 g	T-10 g	T-10 g	T-12 i	T-12	T-12 i	T-12 i	PG-17	PG-17	PG-17
Base	Recess DC	Recess DC	Recess DC	Recess DC	Recess DC	Recess DC	Recess DC	Recess DC	Recess DC	Recess DC
Approx. lamp current (amperes)	1.5	1.5	1.5	1.5	1.5	1.52	1.5	1.5	1.5	1.5
Approx. lamp volts	80	120	160	84		125	163	84	125	63
Approx. lamp watts f	105 h	150 h	205 h	116		168	215	116	168	215
Rated life (hours) b	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000
Lamp lumen depreciation (LLD) c	66	66	66	69		72	72	69	69	69

Figure 5.3.11 Technical Data: Typical Hot-Cathode Fluorescent Lamps (Rapid Starting) a (cont'd)

	Highly Loaded Lamps (cont'd)									
Initial lumens d										
Cool white	6700 h	10000 h	14000 h	6900	8950	10640	15250	7450	11500	16000
Deluxe cool white	4690 h	7000 h	9800	4900		7400	10750	5200		12000
Warm white				6700		10500	14650	7000		15000
White						10500	15000			
Daylight				5700		9300	12650	6000	9300	13300
Factors for calculating luminance e										
Candelas per square metre	3.18	2.04	1.49	2.65	2.1	1.7	1.24	1.91 j	1.2 j	0.89 j
Candelas per square foot	0.30	0.19	0.14	0.25	0.20	0.16	0.12	0.18 j	0.11 j	0.08 j

a The life and light output rating of fluorescent lamps are based on their use with ballasts that provide proper operating characteristics. Ballasts that do not provide proper electrical values may substantially reduce either lamp life or light output or both.
b Rated life under specified life conditions with three hours per start. At longer burning intervals per start, longer life can be expected.
c Per cent of initial light output at seventy per cent rated life at three hours past start. Average for cool white lamps. Approximate values.
d At 100 hours. Where lamp is made by more than one manufacturer light output is the average of manufacturers. For the lumen output of other colours of fluorescent lamps, multiply the cool white lumens by the relative light output value from the below table.
e To calculate approximate lamp luminance, multiply the lamp lumens of the lamp colour desired by the appropriate factor. Factor derived using method by E.A. Lindsay, "Brightness of Cylindrical Fluorescent Sources", Illuminating Engineering, Vol. XXXIX, January 1944, p. 23.
f Includes watts from cathode heat.
g. A jacketed T-10 design is also available for use in applications where lamps are directly exposed to cold temperatures.
h. Peak value. At 25°C (77°F) lumen and wattage values are lower.
i. These lamps available in several variations (outdoor, low temperature, jacketed) with the same, or slightly different, ratings.
j. Average luminance for centre section of lamp. Parts of surface of lamp will have high luminance.
k. Initial lumens for 3100 K and 4100 K colour lamps (GTE Sylvania) are: 25-W, 2150; 32-W, 2900; and 40-W, 3650.

Note: All electrical and lumen values apply only under standard photometric conditions.

Figure 5.3.11 Technical Data: Typical Hot-Cathode Fluorescent Lamps (Rapid Starting) a (cont'd)

Approximate Relative Light Output of Various Fluorescent Lamp Colours Compared to Cool White					
Blue	0.04 3/4		Colour 86	(Phillips Electronics, Canada)	1
Green	1.38 3/4				
Pink	0.37 3/4A		High CRI, 5000 k	0	
Gold	0.72 3/4		Chroma 50 (GE), Colortone 50 (North American Phillips) and Colour-Matcher 50, Colour Classer 50, Optima Magnalux (Duro-Test).		
Red	0.06 3/4				
Natural*	0.67 3/4		High CRI, 7500 k	0.6	
Soft white (new-3000 K)	3/4B		Chroma 75 (GE), Colortone 75 (North American Ph Lamp), and Colour Classer 75, and Color-Matcher 75 (Duro-Test).		
Cool green	0.83 3/4				
Incandescent/Flourescent	(GTE Sylvania)	0.55	Lite White †	(GE, North American Phillips and GTE Sylvania)	0.6
Modern White Deluxe	(North America Phillips Lamp)	0.77			
Sign White	(GE)	0.76	Royal White	(GTE Sylvania)	1.03
Design White	(GTE Sylvania)	0.78	Regal White	(GE)	0.90
Supermarket White	(North American Phillips Lamp)	0.74			
Optima 32	(Duro-Test)	0.76			
Super White	(Duro-Test)	0.93			
Turquoises	(Duro-Test)	0.96			
Super Deluxe 45	(Duro-Test)	0.79			
Daylight 65	(Duro-Test)	0.65			
Vita-Lite, Vita-Lux	(Duro-Test)	0.69			
Ultralume 83, 84, 85	(North American Phillips Lamp)	0.92			
Lite White Deluxe	(GTE Sylvania)	1.0			
3 K	(GTE Sylvania)	1.0			

* Formerly, soft white/natural.

† Currently available in energy saving fluorescent lamps only. Consult the lamp manufacturers for the availability and the lumen output of colours in other lamp sizes.

The colours in groups A and B are made by most lamp manufacturers for and in several lamp sizes. The balance of the lamp colour generally made by just one lamp company and in just a few lamp sizes. Practically all colours are made in the 40-watt preheat start/rapid start size. Consult the lamp manufacturers for the availability and lumen output of colours on other lamp sizes.

Figure 5.3.11 Technical Data: Typical Hot-Cathode Fluorescent Lamps (Rapid Starting) a (cont'd)

Manufacturers Lamp Designation	Lamp Watts	Maximum Overall Length (mm)	Maximum Overall Length (inches)	Bulb	Base	Approximate Lamp Current Amperes	Approximate Lamp Voltage Volts	Rated Life	Initial Lumens h	Lamp Lumens Depreciation (L.L.D)	Colour Rendering Index
Dulux e	5	105	4 1/8	T-4 k	G23	0.18	40	10000	250	--	86
F7TT/SPX27 b 3/4	7	135	5 5/16	T-4 k	G23	0.18	45	10000	400	83	84
F7TT/27K d 3/4 Dulux e 3/4											
PL7/82 c	7	133	5 1/4	T-4 m	G23	0.18	45	10000	400	--	82
F9TT/SPX27 b 3/4	9	167	6 9/16	T-4 k	G23	0.23	59	10000	600	85	84
F9TT/27K d 3/4 Dulux e 3/4											
PL9/82 d	9	165	6 1/2	T-4 m	G23	0.18	59	10000	600	--	82
Dulux-D e	9	116	4 9/16	T-4 k	G24	0.185	66	10000	600	--	85
PL13/82 c	13	188	7 7/16	T-4 m	GX23	0.30	60	10000	900	--	82
F13TT/27K d	13	188	7 7/16	T-4 k	GX23	0.30	60	10000	900	--	82
Dulux e	13	177	6 31/32	T-4 k	GX23	0.30	60	10000	900	--	86
Dulux-D 3	13	146	5 3/4	T-4 k	G24	0.175	92	10000	900	--	85
2D g	16	135	5 5/16	T-4 q	r	0.20	97	10000	1050	--	82
Dulux e	17	170	6 11/16	T-4 k	G24	0.24	106	10000	1250	--	85
SL-18 c	18	183	7 3/16	n	Med.	0.24	--	7500	1100	--	81
Delux-T5 e	18	251	9 7/8	T-5	TBA	0.38	57	10000	1250	--	85
FBU19T8 f	19	222	8 3/4	T-8 o	Med.	--	--	7500	p	--	--
Dulux T5 e	24	362	14 1/4	T-5	TBA	0.34	91	10000	2000	--	85
Dulux-D e	25	190	7 1/2	T-4 k	G24	0.30	114	10000	1800	--	85
Dullux T5 e	35	443	17 7/17	T-5	TBA	0.43	108	10000	2900	--	85

a At three hours per start
b General Electric
c North American Phillips Lighting
d GTE Sylvania
e Osram
f Interlectric
g Thom EMI
h 2700k colour
k U-shaped molded with square corners
m Twin-tube with small connection on top
n U-shaped bent into another U-shape with enclosing plastic housing
o U-shaped band
p Bent to appear as two joined D shapes
q Special recessed 2-pin base
r Cool white 665, Warm white 675 and Tru-lite 520

Figure 5.3.12 Technical Data: Compact Fluorescent Lamps

Manufacturers' Designation ANSI Designation	48T8 25 mm		45 inch	72T8 25-mm		69-inch	96T8 25-mm		93-inch	U6-96T8 (hairpin) d --		
Lamp length a												
Millimetres		1125			1725			2325			1125 d	
Inches		45			69			93			45 d	
Lamp base		Ferrule			Ferrule			Ferrule			Ferrule	
Bulb		25-mm, T-8			25-mm, T-8			25-mm, T-8			25-mm, T-8	
Open circuit volts (rms) for starting												
Type L.P.		450			600			750			750	
Type H.P.		600			750			835			835	
Lamp current (milliamperes) b	120	150	200	120	150	20	120	150	200	120	150	20
Lamp voltage-lamp type L.P.	250	240	--	330	310	--	420	400	--	420	400	--
Lamp voltage-lamp type H.P.	270	250	240	350	330	310	450	425	400	450	425	400
Lamp power (watts)												
Type L.P.	26	30	--	34	40	--	42	49	--	42	49	--
Type H.P.	28	33	40	37	43	52	46	54	65	46	54	65
Initial lumens												
Warm white c	1100	1300	1600	1700	2000	2350	2300	2700	3400	2300	2700	3400
White (3500 K) c	1050	1250	1550	1650	1900	2300	2250	2650	3300	2250	2650	3300
White (4500 K) c	1000	1200	1500	1600	1850	2200	2200	2600	3200	2200	2600	3200
Daylight c	950	1150	1450	1550	1809	2150	2150	2550	3100	2150	2550	3100
Luminance (candelas per square metre)												
Warm white	4040	4800	5860	4350	5140	6100	4490	5240	6610	4490	5240	6610
White (3500)	3940	4590	5690	4250	5040	5930	4385	5140	6440	4385	5140	6440
White (4500)	3770	4385	5480	4145	4930	5650	4280	5070	5820	4280	5070	5820
Daylight	3770	4210	5310	4080	4830	5480	4210	4970	5650	4210	4970	5650
Rated lamp life (thousands of hours) e												
Type L.P.	15	12.5	--	15	12.5	--	18	16	--	18	16	--
Type H.P.	25	20	15	25	20	15	30	25	20	30	25	20

a Length of lamp without lamp holders
b Lamps can be operated up to 200 mA.
c Initial rating after 100 hours for types L.P. and H.P. Other colour lamps are available.
d Extended lamp length 2325 millimetres (93 inches) formed to U-shape with 180-degree, 150-millimetre (6-inch) arc.
e Life not affected by number of starts.

Figure 5.3.13 Technical Data: Typical Cold-Cathode Fluorescent Lamps

Nominal lamp watts	4	6	8	13	14	15	15	20	25	25	30	40	
Nominal length													
(millimetres)	50	225	300	525	375	450	450	600	700	825	900	1200	
(inches)	6	9	12	21	15	18	18	24	28	33	36	48	60
Bulb	T-5 (16 mm)	T-5 (16 mm)	T-5 (16 mm)	T-5 (16 mm)	T-12 (38 mm)	T-8 (38 mm)	T-12 (38 mm)	T-12 (38 mm)	T-12 (38 mm)	T-12 (38 mm)	T-8 (25 mm)	T-12 (38 mm)	or T-17
Base (bipin)	min.	min.	min.	min.	med.	med.	med.	med.	med.	med.	med.	med.	
Approx. lamp current (amperes)	0.17	0.16	0.145	0.165	0.38	0.305	0.325	0.38	0.46	0.46	0.355	0.43	
Approx. lamp volts	29	42	57	95	40	55	47	57	63	61	99	101	
Approx. lamp watts	4.5	6.0	7.2	13	14	14	14.5	20.5	25	25.5	30.5	40	
Preheat current-max. amperes	0.25	0.25	0.25	0.27	0.65	0.65	0.65	0.65	0.95	0.95	0.65	0.75	
Preheat current-min. amperes	0.16	0.16	0.16	0.18	0.44	0.44	0.44	0.44	0.41	0.42	0.40	0.55	
Rated life (hours) b	6000	7500	7500	7500	9000	7500	9000	9000	7500	7500	7500	20000	9000
Lamp lumen depreciation (LLD) c	67	67	75	72	82	79	81	85	79	79	79	82	85
Initial lumens d													
Cool white	138	293	400	833	687	873	793	1270	1725	1915	2200	3150	
Deluxe cool white	105	205	280	---	---	610	537	858	---	---	1555	2200	
Warm white	127	290	400	880	710	880	800	1310	---	1935	2235	3175	
Deluxe warm white	85	180	275	580	476	610	532	848	---	---	1505	2165	
White	138	272	405	880	710	880	800	1290	---	1925	2255	3185	
Daylight	115	230	333	750	593	750	650	1050	1450	1636	1900	2615	
Factors for calculating luminance													
Candelas per square metre	78.9	44.4	31.4	15.2	10.3	12.0	8.0	5.5	4.68	3.93	5.4	2.65	2.1, 1.5 f

a The life and light output ratings of fluorescent lamps are based on their use with ballasts that provide operating characteristics. Ballasts that do not provide proper electrical values may substantially reduce either lamp life or light output, or both.
b Rated life under specified test conditions at three hours per start. At longer burning intervals per start, longer life can be expected.
c Per cent of initial light output at 70% rate life at 3 hours per start. Average for cool white lamps. Approximate values.
d At 100 hours. Where lamp is made by more than one manufacturer, light output is the average of manufacturers. For the lumen out of other colours of fluorescent lamps, multiply the cool white lumens by the relative light output value from the table below Figure 11.
e To calculate approximate lamp luminance, multiply the lamp lumens of the lamp colour desired by the appropriate factor.
f First factor is for the T-12 lamp; second factor is for the T-17 lamp.

Note: All electrical and lumen values apply only under standard photometric conditions.

Figure 5.3.14 Technical Data: Typical Hot-Cathode Fluorescent Lamps (Preheat Starting) a (published by permission of IESNA)

Nominal length (millimetres)	1050	1600	1800	2400	1200	1500	600	900	1050	1200	1500	1600	1800	21	
(inches)	42	64	72	96	48	60	24	36	42	48	60	64	72	84	96
Bulb	T-6	T-6	T-8	T-8	T-12	T-17	T-12	T-12	T-12	T-12	T-12	T-12	T-12	T-12	T-12
Base	Single Pin	Single Pin	Single Pin	Single Pin	Med. Pin	Mog. Pin	Single Pin	Single Pin	Single Pin	Single Pin	Single Pin	Single Pin	Single Pin	Single Pin	Single Pin
Approx. lamp current (amperes)	0.200f	0.200f	0.200f	0.200f	0.425	0.425	0.425	0.425	0.425	0.425	0.425	0.425	0.425	0.425	0.425
Approx. lamp volts	150	233	220	285	104	107	53	77	88	100	123	131	149	17	
Approx. lamp watts	25.5	38.5	38	51	40.5	42	21.5	30	34.5	39	48	50.5	57	66	
Rated life (hours) b	7500	7500	7500	7500	7500-12000	7500-9000	7500-9000	7500-9000	7500-9000	7500-12000	7500-12000	7500-12000	7500-12000	7500-12000	12000
Lamp lumen depreciation (LLD) c	76	77	83	89	83	89	81	82	80	82	78	78	89	91	89
Initial lumens d															
Cool white	1835	3000	3030	4265	3100	2900	1065	2000	2350	3000	3585	3865	4650	5400	
Delux cool white	1267	2100	2100	2910		2020				2065			3175		
Warm white	1875	3050	3015	4215	3150	2940	1150	2050	2500	3000		3950	4675		
Deluxe warm white	1275	2100				1990				2050		3950	4675		
White	1900	2945	3050	4225	3150	2940				3000			3200		
Daylight	1605	2600	3650	3525	2565	2410	1010	1715	2015	2500	3135	3250	3850	4450	
Factors for calculating luminance															
Candelas per square metre e	6.1	3.93	2.55	1.87	2.65	1.5	5.54	3.58	3.04	2.65	2.1	1.95	1.7	1.44	1.24

a The life and light output ratings of fluorescent lamps are based on their use with ballasts that provide operating characteristics. Ballasts that do not provide proper electrical values may substantially reduce either lamp life or light output, or both.

b Rated life under specified test conditions at three hours per start. At longer burning intervals per start, longer life can be expected.

c Per cent of initial light output at 70% rate life at 3 hours per start. Average for cool white lamps. Approximate values.

d At 100 hours. Where lamp is made by more than one manufacturer, light output is the average of manufacturers. For the lumen out of other colours of fluorescent lamps, multiply the cool white lumens by the relative light output value from the table below Figure 11.

e To calculate approximate lamp luminance, multiply the lamp lumens of the lamp colour desired by the appropriate factor.

f First factor is for the T-12 lamp; second factor is for the T-17 lamp.

Note: All electrical and lumen values apply only under standard photometric conditions.

Figure 5.3.14 Technical Data: Typical Hot-Cathode Fluorescent Lamps (Preheat Starting) a (published by permission of IESNA) (cont'd)

Lamp Designation	Nominal Length (mm)	Nominal Length (inches)	Minimum Required rms Voltage across Lamp for Reliable Starting a	Operating Current (Milliamperes)	Approximate Watts Consumed i: Lamp	Single Lamp Circuit: Ballast	Single Lamp Circuit: Total	Two Lamp Circuit: Ballast	Two Lamp Circuit: Total
Preheat Start									
4T5	150	6	b	170	4.5	2	6.5		
6T5	225	9	b	160	6	2	8		
8T5	300	12	b	145	7.2	2	9.2		
15T8	450	18	b	305	15	4.5	19.5	9	39
14T12	375	18	b	380	14	5	19	5	33
15T12	450	18	b	325	14.5	4.5	19	9	38
20T12	600	24	b	380	20.5	5	25.5	10	41
25T12	825	33	b	460	25.5	6	31.5		
13T5	525	21	180	165	12	5	18		
30T8	900	36	176	355	30.5	10.5	41	17	78
40T12	1200	48	176	430	40	12	52	16	96
90T17	1500	60	132	1500	90	20	110	24	204
Instant Start with Bipin Bases									
40T12	1200	48	385	425	40.5	23.5	64	25	106
40T12	1500	60	385	425	42	24	66		
40T17	1500	60	385	425	42	24	66	26	110
With Single Pin Bases (Slimline Lamps)									
42T6 d	1050	42	405	200	25.5	13	38.5	21	72
64T6 d	1600	64	540	200	38.5	16	54.5	22	99
72T8 d	1800	72	540	200	38	16	54	31	107
96T8 d	2400	96	675	200	51	16	67		
48T12 (lead-lag)	1200	48	385	425	39			26	104
(Series)	1200	48	385	425	39			17	95
72T12 (lead-lag)	1800	72	475	425	57			47	161
(Series)	1800	72	475	425	57			25	139
96T12 (lead-lag)	2400	96	565	425	75			40	190
(Series)	2400	96	565	425	75			22	172
96T12	2400	96	565	425	75				160
96T12	2400	96	565	440	60				128
Rapid Start c									
Lightly Loaded									
20T9 e	165	6 1/2	150	380	19	11.5	30.5		
22T9 e	210	8 1/4	180	370	22.5	11.5	34		
25T8	900	36	170	265	25	5	30	8	58
28T12 j	1200	48	231	330	28				60
32T8	1200	48	200	265	32	5	37	7	71
32T10 e	305	12	200	425	33	12	45		
40T10 e	406	16	205	415	41.5	12.5	54		
30T12	900	36	150	430	33.5	10.5	44		
"32"T12 j	1200	48			32				76
40T8	1500	60	250	265	40	6	46	11	91
40T10	1200	48	200	420	41	13	54	13	95
40T12	1200	48	200	430	41	13	54	13	95

Figure 5.3.15 Technical Data: Fluorescent Lamp Power Requirements (published by permission of IESNA)

Lamp Designation	Nominal Length (mm)	Nominal Length (inches)	Minimum Required rms Voltage across Lamp for Reliable Starting a	Operating Current (Milliamperes)	Approximate Watts Consumed i: Lamp	Single Lamp Circuit: Ballast	Single Lamp Circuit: Total	Two Lamp Circuit: Ballast	Two Lamp Circuit: Total
40W-U3 f	600	24	200	420	41	13	54	13	95
40W-U6 f	600	24	200	430	40.5	13	53.5	13	94
Medium Loaded									
24T12	600	24	b	800	37		70		115
48T12	1200	48	155	800	63		85		146
72T12	1800	72	260	800	87		106		200
84T12	2100	84	280	800	100		119		213
96T12	2400	96	296	800	113		140		252
Highly loaded									
48T12, 48PG17	1200	48	160	1506	116		146		252
72T12, 72PG17	1800	72	225	1500	168		213		326
96T12, 96PG17	2400	96	300	1500	215		260		450
Cold Cathode									
96T8LP	2400	96	750	120	42	9	51	17	101
				150	49				
				200	59	19	78	30	148
96T8HP	2400	96	835	120	46	12	58	24	115
				150	54			28	136
				200	65			30	160
Using Enengy Ballasts g									
Rapid Start c									
40T12	1200	48	200	430	40	7	47	6	84
40T12 h	1200	48	200	460	34-35		41		74
Slimline									
96T12	2400	96	565	425	75				160
96T12 h	2400	96	565	440	60				128
Rapid Start c									
Medium Loaded									
96T12	2400	96	296	800	113				237
96T12 h	2400	96	296	840	95				207

a Between 10°C (50°F) and 43°C (110°F). The voltage shown is that required across one lamp. A ballast to operate two rapid start lamps in series will require an open circuit voltage rougly 40% higher than shown here. Consult lamp manufacturer for information.

b Suitable for operation on 120-watt ac lines with series reactor as ballast.

c Requires starting aid.

d T-6 and T-8 slimline lamps also operate at 120 and 300 milliamperes.

e Circular lamp-dimension given is nominal outside diameter.

f U-shaped lamp.

g Energy saving CBM-rated ballasts are designed to operate standard fluorescent lamps at CBM rated light output with lower ballast losses than the usual fluorescent lamp ballasts. The data shown here are typical for this type for ballast of the three most common fluorescent lamps and the energy-saving fluorescent lamp that can be used as a replacement.

h Energy saving fluorescent lamp.

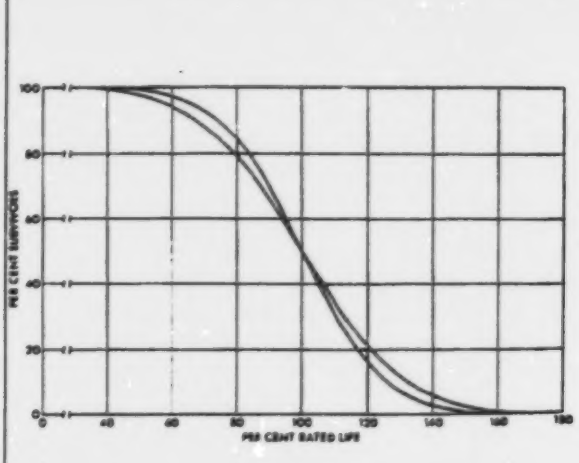
i Lamp watts and light output will vary with lamp operation.

j Cathode-cutout type.

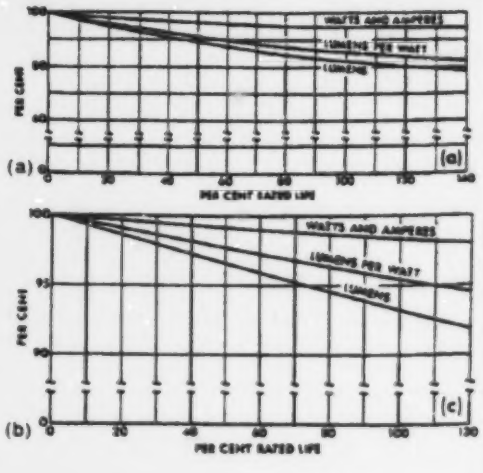
Figure 5.3.15 Technical Data: Fluorescent Lamp Power Requirements (published by permission of IESNA) (cont'd)

5.3.5 Operational Characteristics Of Typical Light Sources

INCANDESCENT



I. Range of typical mortality curves (average for a statistically large group of good quality incandescent filament lamps).

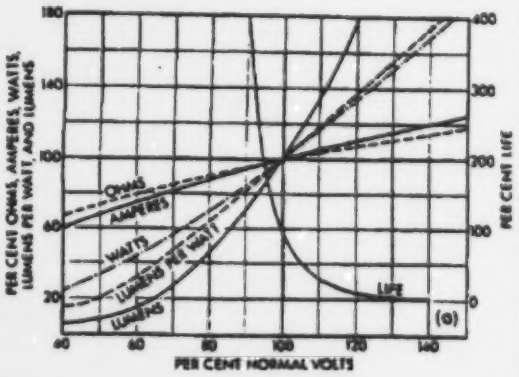


II. Typical operating characteristics of lamps as a function of burning time: (a) general service lamps and operating characteristics of a tunsten-halogen lamp are shown in (b). (*Note differences in scales.*)

Soft Glass Bulb	300°C
Hard Glass Bulb	435°C-475°C
Cemented Base	
Regular	175°C
Special "Hi-Temp"	230°C
Mechanical Base	215°C
Bipost Base	285°C

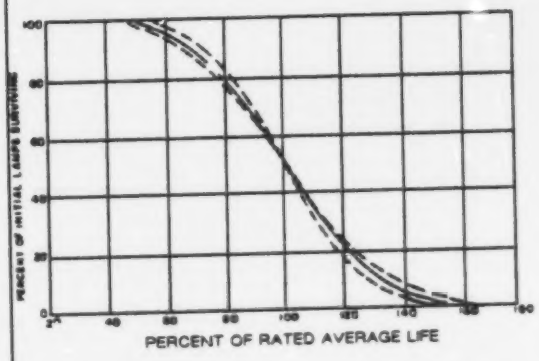
MAXIMUM SAFE OPERATING TEMPERATURES
(Approximate Figures)

III.

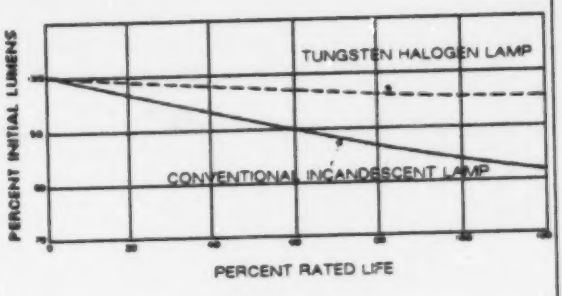


IV. Effect of voltage and current variation on the operating characteristics of: (a) incandesent filament lamps in general lighting (multiple) circuits and (b) incandescent filament lamps in series street lighting circuits.

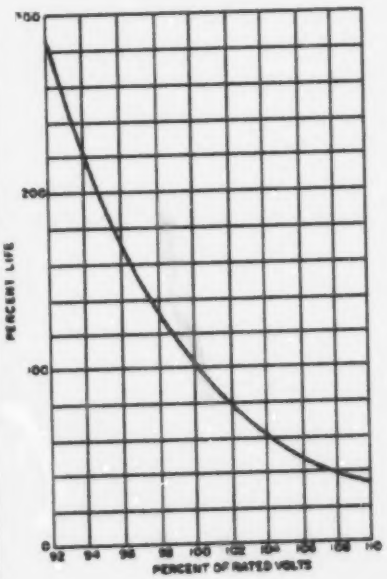
Figure 5.3.16 Operating Characteristics of Typical Incandescent Lamps



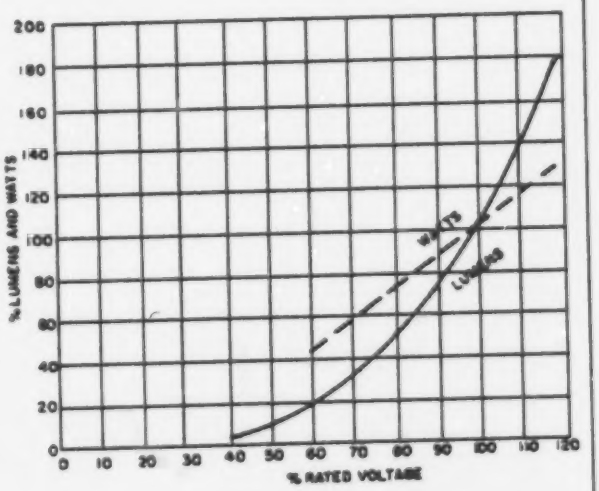
I. Life expectancy curve for Tungsten Halogen lamps.



II. Typical lumen maintenance curves.



III. Typical life variation with volts for Tungsten Halogen lamps.



IV. Typical wattage and lumen variations with volts for Tungsten Halogen lamps.

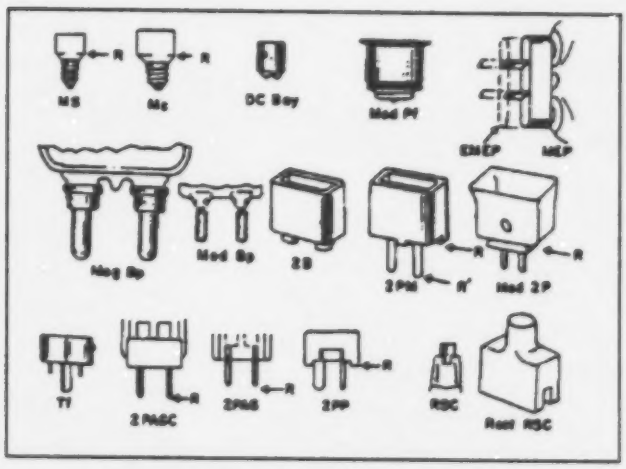
Figure 5.3.17 Operating Characteristics of Typical Tungsten Halogen Lamps

Operating Instructions

Keep lamp seal temperature below 343°C and bulb wall temperature above 260°C. This lamp is designed for operation in circuits not exceeding rated voltage. This lamp should be burned in sockets and equipment approved for its use. Handle lamp only with wrapper attached. If necessary to touch lamp during installation, clean the quartz with alcohol and dry with clean, soft cloth before operation. Contamination of the quartz may result in reduced lamp performance.

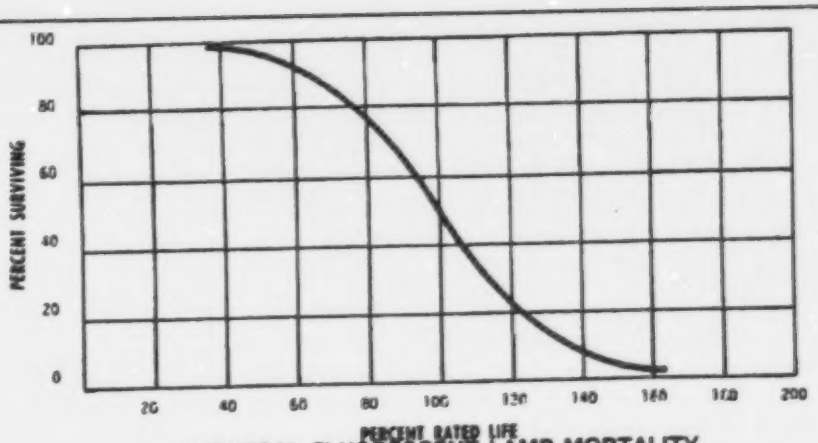
CAUTION: OPERATES UNDER PRESSURE AND MAY SHATTER

Use in equipment with a suitable screen to protect people and surroundings. Do not operate in close proximity to persons, combustable materials or substances affected by heat or drying. Do not operate over 110% rated voltage because such operation increased pressure, tendancy to shatter and ultraviolet output which may cause skin and eye irritation with prolonged exposure. Protect bulb from abrasions and scratches. Do not insert lamp when power is on. Follow operating instructions.

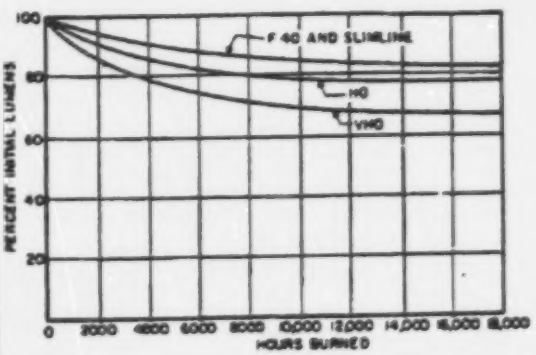


V. Common Tungsten Halogen lamp bases.

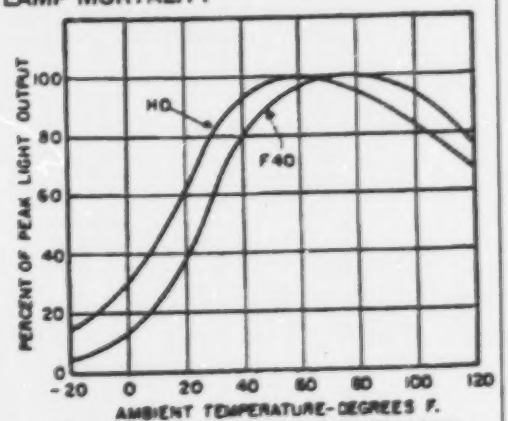
Figure 5.3.17 Operating Characteristics of Typical Halogen Lamps



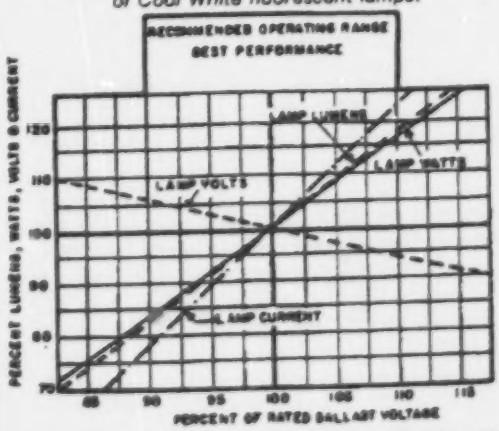
I. TYPICAL FLUORESCENT LAMP MORTALITY



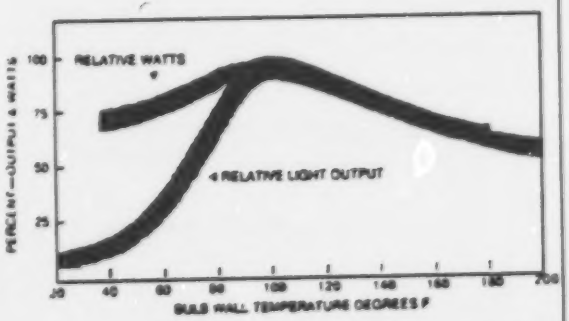
II. Approximate lumen maintenance of various types of Cool White fluorescent lamps.



III. Changes in light output with ambient temperature for bare fluorescent lamps in still air.

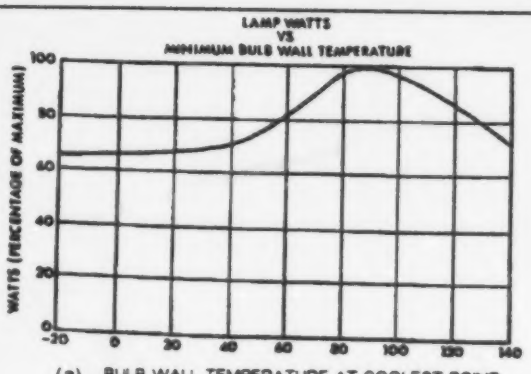


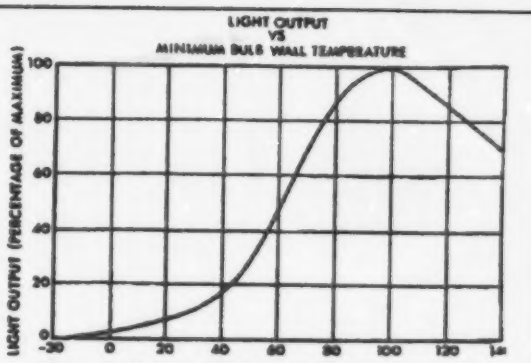
IV. Effect of voltage on lamp volts, amperes, watts and lumens with 2-lamp series rapid start ballast.



V. Light output and wattage of fluorescent lamps vary as bulb wall temperature varies from the optimum of 100°F.

Figure 5.3.18 Operating Charcteristics of Typical Fluorescent Lamps





VI. Tube Wall Temperature vs. Lamp Wattage and Output.

Average Life in Hours of Fluorescent Lamps at Various Burning Cycles

Lamp Type	Hours Per Start					
	3	6	10	12	18	Cont.
40W Preheat	12000	14000	17000	18000	20000	22500
40W Rapid Start	18000	22000	25000	26000	28500	34000
High Output (HO)	12000	14000	17000	18000	20000	22500
Very High Output (VHO)	9000	11300	13500	14400	16200	22500
Slimline (96T12)	12000	14000	17000	18000	20000	22500

Representative Fluorescent Lamp Ballast Factors

Lamp	Ballast		
	Standard	Low Loss	High Performance
4-Floor Rapid Start System (F40T12)			
Standard	0.95	0.95	0.97
Reduced Wattage	0.89	0.87	0.95
8-Foot Slimline Systems (F96T12)			
Standard	0.94	0.93	0.97
Reduced Wattage	0.87	0.85	0.96
8-Foot High Output Systems			
Standard	0.98	—	1.03
Reduced Wattage	0.93	—	0.98

Figure 5.3.18 Operating Characteristics of Typical Fluorescent Lamps (cont'd)

Approximate Input Watts Fluorescent Lamp Ballast

Lamp Designation	Nominal Watts	120 Volts			347 Volts	
		Single Lamp	Two-Lamp		Single Lamp	Two-Lamp
			Series	Lead-Lag		Series
Preheat						
F4T5	4	6	—	—	—	—
F6T5	6	8	—	—	—	—
F8T5	8	10	—	—	—	—
F13T5	13	19	—	—	—	—
F14T12 1	14	29	44	—	31	44
F15T8 1	15	31	53	—	32	53
F15T12 1	15	31	52	—	32	52
F20T12 1	20	35	57	—	36	57
F25T12	25	31	—	—	—	—
F30T8	30	40	—	—	—	—
F40T12	40	50	—	—	—	—
F90T17	90	110	—	211	—	—
Rapid Start						
F30T12	30	44	79	—	44	75
F40T12	40	57	98	—	56	93
High Output						
F24T12	32	—	132	—	—	135
F48T12	60	93	150	—	—	166
F72T12	85	117	199	—	—	198
F96T12	110	138	248	—	—	250
Very High Output						
F48T12/VHO	115	160	267	—	—	267
F72T12/VHO	165	205	370	—	—	370
F96T12/VHO	215	265	480	—	—	480
Circline						
FC8T9	22	27	—	—	—	—
FC12T10	32	44	—	—	—	—
FC16T10	40	56	—	—	—	—
Instant Start						
F40T12/IS	40	64	108	—	—	110
F40T17/IS	40	64	108	—	—	110
Slimline						
F42T6 2	26	41	74	—	—	—
F64T6 2	38	55	103	—	—	—
F72T8	38	55	104	—	—	—
F96T8 2	51	68	129	—	—	—
F48T12 3	39	64	103	108	—	110
F72T12 3	55	83	140	146	82	147
F96T12 3	75	99	180	178	98	176

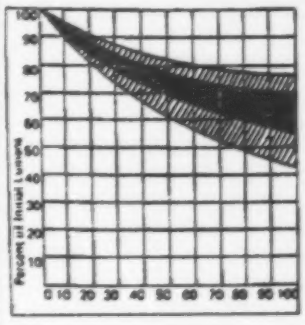
1. Rapid Start Ballast
2. Operating lamp at 200 ma.
3. Operating lamp at 425 ma.

Figure 5.3.18 Operating Characteristics of Typical Fluorescent Lamps (cont'd)

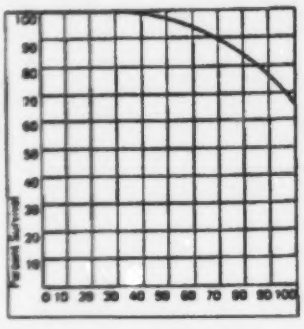
Nominal Lamp Wattage	Lamp Type **	Nominal Arc Length Inches	Operating Volts (Nom.)	Operating Current Amps, Nom	Starting Current (Amps, Min-Max)	Maximum Ballast Open Circuit Voltage		Minimum Ballast OCV to Start Lamp @		
						1st. Sec.	After	50°F	0°F	-20°F
40	H45	5/8	90	.53	.53-1.12	RMS --	355	160x	175x	180
						Peak 750	TBD	226	247	255
50	H46	5/8	90	.6	.6-1.26	RMS --	528	200	200	210
						Peak 750	TBD	283	283	297
75	H43	1	130	.66	.66-1.4	RMS --	528	200x	201x	225
						Peak 750	TBD	283	297	318
100	H44	1 1/8	130	.85	.85-1.85	RMS --	450	200x	210x	225
						Peak 1100	1100	283	297	318
100	H38	1 1/8	130	.85	.85-1.85	RMS --	450	200x	210x	225
						Peak 1100	1100	283	297	318
175	H39	2	130	1.5	1.5-3.25	RMS --	450	200x	210x	225
						Peak 1100	1100	283	297	318
250	H37	2 1/8	130	2.1	2.1-4.5	RMS --	450	190x	210x	225
						Peak 1100	1100	269	297	318
400	H33	2 3/4	135	3.2	3.1-7.5	RMS --	450	190x	210x	225
						Peak 2150	2150	269	297	318
700	H35	5	265	2.8	2.8-6.7	RMS --	800	215x	325x	410*
						Peak 2150	2150	304	460	580*
1000	H34	5	135	8	8-17.8	RMS --	450	200	325	410*
						Peak 2150	2150	283	460	580*
1000	H36	6	265	4	4-9.5	RMS --	800	215x	325x	410*
						Peak 2150	2150	304	460	580*

** Electrical Identification.

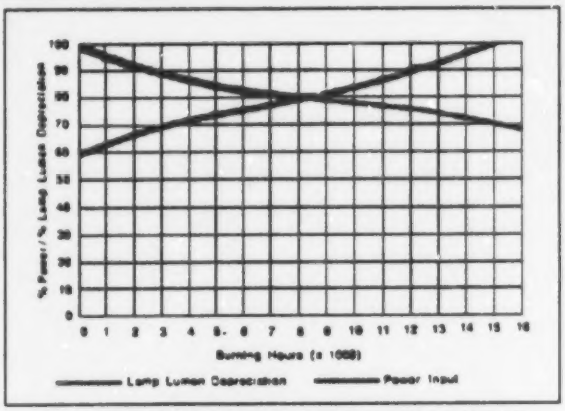
Figure 5.3.19 Operating Characteristics of Typical Mercury Lamps



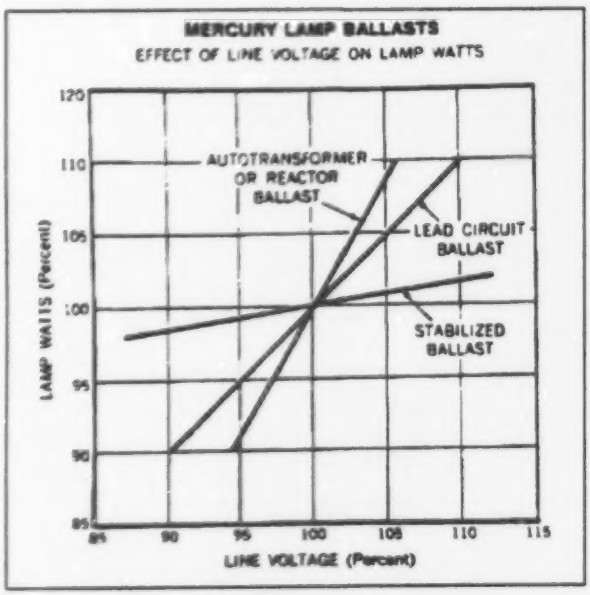
I. Percent of Rated Average Life Lumen Maintenance for Mercury Lamps



II. Percent of Rated Average Life Approximate Survival Mercury Lamps



III. (Note: Lighting system is designed according to standard procedure to provide a specified maintained footcandle level at a specified number of burning hours. The relamp signal will correspond approximately with the relamp interval for which the system was designed, assuming that all depreciation factors were correctly calculated.)



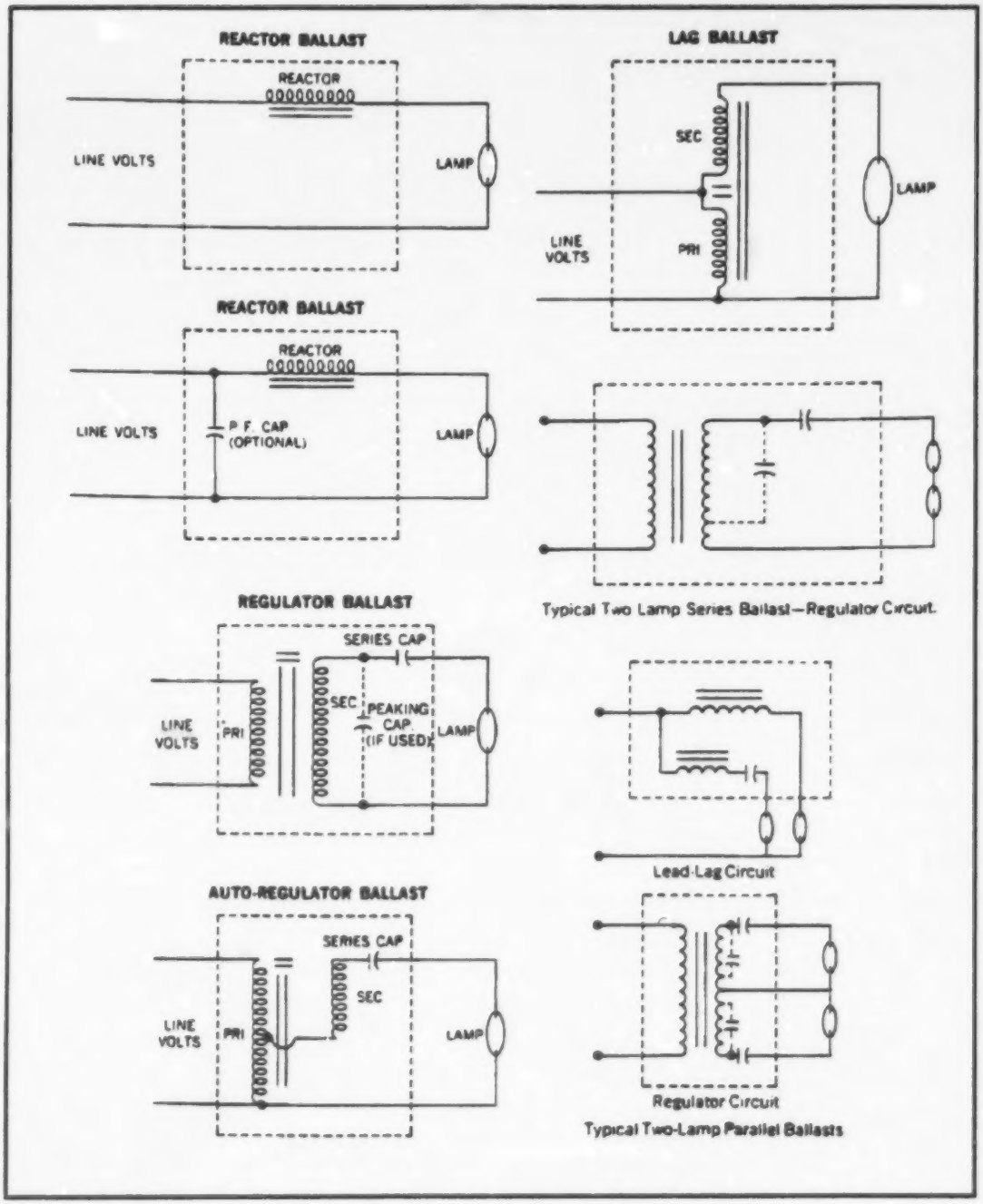
IV.

Figure 5.3.19 Operating Characteristics of Typical Mercury Lamps (cont'd)

Volts	Watts	Bulb	Base	Average Rated Life Hours	Approximate Lumens for Vertical Operation	
					Initial	Mean 3
Solid State Starting Self-Ballasted Lamps[1]						
120	160	E-23 1/2	Medium Skirted	20000	2700	1910
120	300	E-28	Medium Skirted	20000	2700	5500
120	300	E-28	Mogul	20000	2700	5500
Conventional Self-Ballasted Lamps[2]						
120	450	BT-37	Mogul	16000	9500	7125
120	750	R-57	Mogul	16000	14000	10500
240	750	R-57	Mogul	16000	14500	12325
208	150	PS-40	Mogul	16000	11500	
230	450	PS-40	Mogul	16000	11500	
208	450	BT-37	Mogul	16000	11500	
230	450	BT-37	Mogul	16000	11500	
208 230 277	750	R-57	Mogul	20000	21700	
208 230 277	1250	BT-56	Mogul	16000	37000	

1. Operating ambient temperature range: 10°C minimum to 50°C maximum.
2. Operating ambient temperature range: −15°C minimum to 50°C maximum.
3. Mean lumens over 16000 hours.

Figure 5.3.19 Operating Characteristics of Typical Mercury Lamps (cont'd)



V. Typical Mercury Lamp Ballast Diagrams.

Figure 5.3.19 Operating Characteristics of Typical Mercury Lamps (cont'd)

Lamp Data

Lamp Watts	ANSI Lamp Designation	ANSI Ballast Number	Approximate Lumens				Bulb	Outer Bulb	Maximum Overall Length Inches	Base	Rated Life (hours)
			Initial (100) Hours		Mean 1						
			Vert.	Horiz.	Vert.	Horiz.					
175	M57PE-175	M57	14000	12000	10800	8300	BT-28 or E-28	Clear	8-5/16	Mog.	7500
175	M57PF-175	M57	14000		10200		BT-28 or E-28	Phos. Coat	8-5/16	Mog.	7500
250	M58PG-250	M58	20500	19500	17000	14000	BT-28 or E-28	Clear	8-5/16	Mog.	10000
250	M58PH-250	M58	20500	19500	16000	13500	BT-28 or E-28	Phos. Coat	8-5/16	Mog.	10000
400	M59PJ-400	M59	34000	32000	25600	22600	BT-37 or E-37	Clear	7	Mog.	15-20000
400	M59PK-400	M59	34000	32000	24600	22600	BT-37 or E-37	Phos. Coat	7	Mog.	15-20000
400	M59PJ-400/ VBD, VUB	M59	40000		31000		BT-37 or E-37	Clear	11-5/16	Mog.	15000
400	M59PK-400/ VBD, VBU	M59	40000		32000		BT-37 or E-37	Phos. Coat	11-5/16	Mog.	15000
1000	M47PA-1000/ BD, BU/I	H36, M47	115000		92000		BT-56	Clear	15-1/16	Mog.	10000
1500	M48PC-1500/	M48	155000		140700		BT-56	Clear	15-3/8	Mog.	3000

1. At 10 or more hours per start except 15000w which is at 5 hours per start.

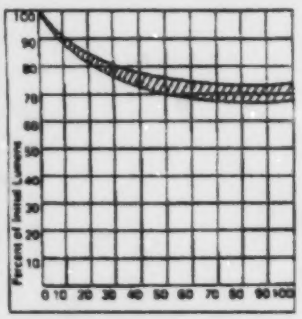
Minimum Ballast Voltage Requirements for Metalarc Lamps

Lamp Watts	Sine-Wave Ballast 1.414 Crest Factor				Typical Lead-Peaked Ballast 1.82 Crest Factor			
	Peak Volts		RMS Volts		Peak Volts		RMS Volts	
	Above 50°F	Below 50°F to -20°F	Above 50°F	Below 50°F to -20°F	Above 50°F	Below 50°F to -20°F	Above 50°F	Below 50°F to -20°F
175	540	540	382	382	540	540	295	295
250	540	540	382	382	540	540	295	295
400	540	540	382	382	540	540	295	295
1000	622	750	440	530	622	750	340	410
1500	622	750	440	530	622	750	340	410

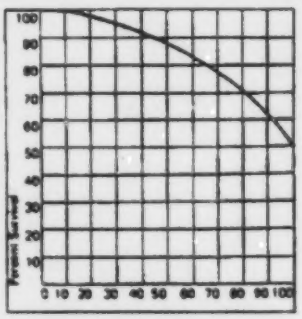
Note: These are minimum requirements for 98% probability of starting at 50°F and 90% probability at -20°F.

Important: Metal-Halide (leak peak) ballasts will operate mercury lamps of equal wattage. Mercury (sine-wave) ballasts will operate metalarc lamps only if the above required peak voltage is available from the ballast at the specified temperatures.

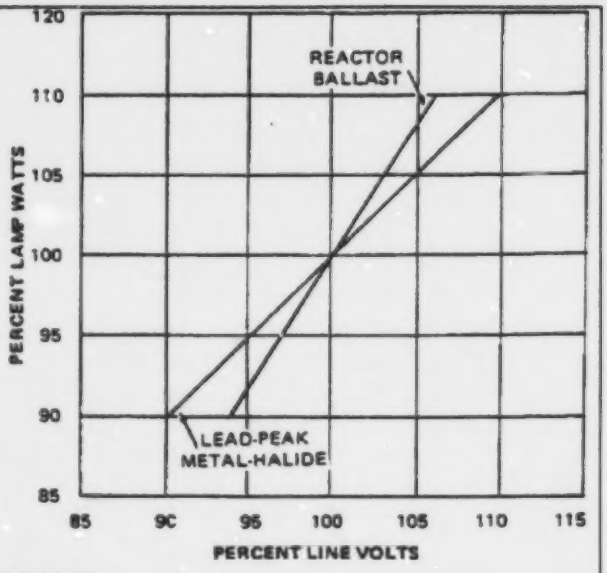
Figure 5.3.20 Operating Characteristics of Typical Metal-Halide Lamps



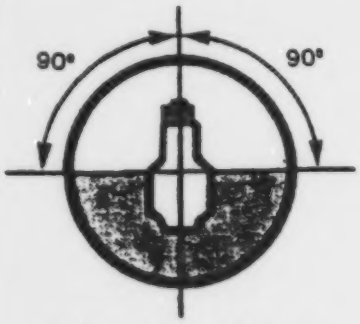
I. Percent of Rated Average Life Lumen Maintenance for Metal Halide Lamps



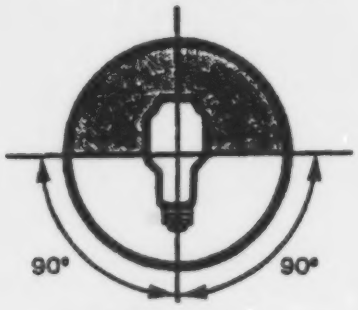
II. Percent of Rated Average Life Approximate Survival Metal Halide Lamps



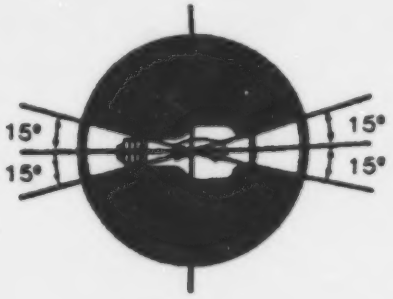
IV. BURNING POSITIONS



BASE UP TO HORIZONTAL (BU–HOR)



BASE DOWN (BD)



HORIZONTAL (HOR)

VERTICAL BASE UP ±15°

VERTICAL BASE DOWN ±15°

UNIVERSAL ±180°

Figure 5.3.20 Operating Characteristics of Typical Metal-Halide Lamps (cont'd)

Lamp Data

Nominal Lamp Wattage	Lamp Type **	Nominal Arc Length Inches	Operating Volts (Nom.)	Operating Current Amps, Nom.	Starting Current (Amps, Min.-Max.)	Maximum Ballast Open Circuit Voltage		Minimum Ballast OCV to Start Lamp @		
						1st. Sec.	After	50°F	0°F	-20°F
150	*C150(3)	2	100	1.78	1.7-3.5	RMS --	TBD	195	195	195
						Peak 4500	4500	2500	2500	2500
250	C*250(3)	3 3/4	100	3.0	3-4.5	RMS --	TBD	198	198	198
						Peak 4500	4500	2500	2500	2500
400	*C400(3)	3 5/16	100	4.6	4.6-7.5	RMS --	TBD	198	198	198
						Peak 4500	4500	2500	2500	2500
1000	*C1000(3)	8 3/4	250	4.7	4.7-7.5	RMS --	TBD	456	456	456
						Peak 5000	5000	5000	3000	3000

1. Values are shown for lamps in vertical operation. Measurements are based on a standard reference ballast.

2. Ballast open circuit voltages are based essentially on ANSI standards or draft standards and apply to linear reactor ballasts. In some cases lower RMS values are permitted with lead-peaked ballasts.

3. ANSI electrical identification: M59 for HM400, M48 for MH1500; S56 for C150, S50 for C250, S51 for C400, S52 for C1000. TBD to be determined.

* ANSI specification to be developed, revised or finalized.

Figure 5.3.21 Operating Characteristics of Typical High Pressure Sodium Lamps

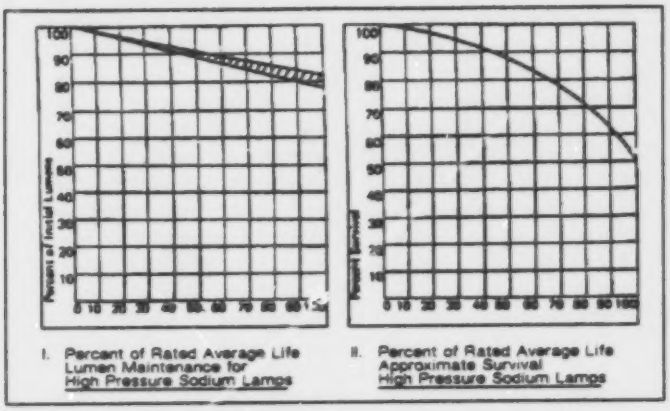

I. Percent of Rated Average Life
Lumen Maintenance for
High Pressure Sodium Lamps
II. Percent of Rated Average Life
Approximate Survival
High Pressure Sodium Lamps

Figure 5.3.21 Operating Characteristics of Typical High Pressure Sodium Lamps (cont'd)

Recommended Operating Temperature Limits*
For Hid Lamps in Open or Enclosed Fixtures

Lamp Type	Outer Bulb	Base
Mercury Vapour	400°C maximum	Mogul screw–210°C maximum other bases–190°C maximum
Metal Halide	400°C maximum	210°C maximum
High Pressure Sodium	400°C maximum	210°C maximum
Self Ballasted (except 160w)	400°C maximum	210°C maximum
160w and Other Soft Glass Sizes	300°C maximum	190°C maximum

* Values recommended by American National Standards Institute (ANSI)

Approximate Ballast Losses

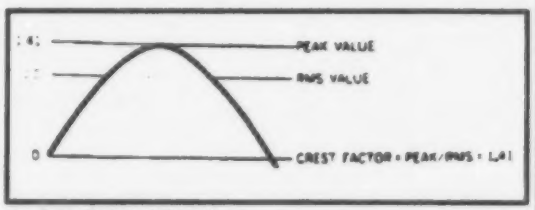
	Loss* % of Rated Lamp Watts
Mercury Vapour	
40w 50w	20–25%
75, 100, 175, 200w	14–20%
400, 700, 1000w	4–13%
Metal Halide	13–17%
400w	5–9%
1000w	
Ceramalux	
150, 250, 400, 1000w	16–21%

* Varies with type of ballast, slightly less for two lamp ballasts

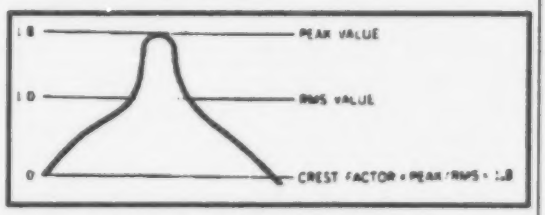
Figure 5.3.22 Miscellaneous Data for HID Lamps

HID Dimming System Performance for Clear Lamps

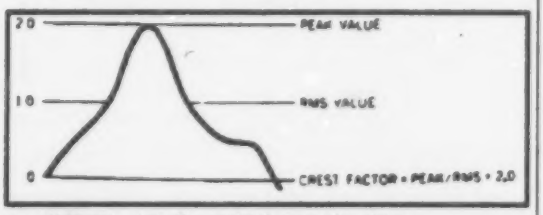
Light Source	Lamp Watts	Minimum Lumen Output (Percent of Full Lumen Output)
Mercury Vapour	100	2
	250	2
	400	2
	1000	3
Metal–Halide	250	20
	400	10
	1000	12
High Pressure Sodium	250	12
	400	10
	1000	20



I. Crest Factor of Sine Wave



II. Distorted Non-Sinusoidal Voltage Waveform.



III. Distorted Non-Sinusoidal Current Waveform.

Figure 5.3.22 Miscellaneous Data for HID Lamps (cont'd)

Electrical and Thermal Data

Lamp Type	Average Lamp Voltage (V)	Average Lamp Current (I)	Minimum Start Voltage (V)	Watts	Life (hours)	Initial Lumens	Maximum Lamp Temp. (°F)	(C)
35W	70	0.60	390	35	18000	4800	209	98
55W	109	0.59	410	55	18000	8000	210	99
90W	112	0.94	420	90	18000	13500	237	114
135W	164	0.95	540	135	18000	22500	210	99
180W	240	0.91	600	180	18000	33000	226	188

BURNING POSITIONS

SOX 35 W
SOX 55 W

SOX 90 W
SOX 135 W
SOX 180 W

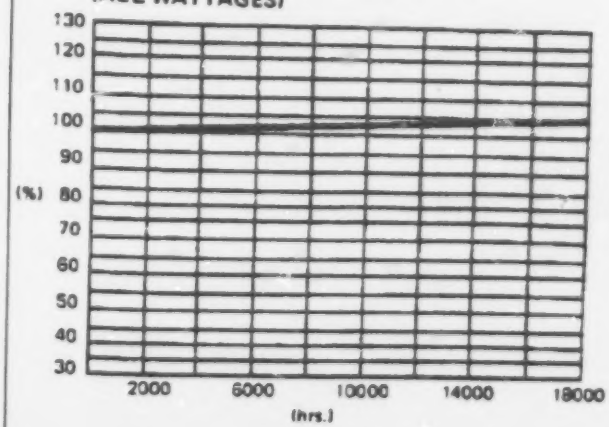
I.

MAXIMUM LAMP TEMPERATURES

Lamp type	°F	°C
SOX 35 W	209	98
SOX 55 W	210	99
SOX 90 W	237	114
SOX 135 W	210	99
SOX 180 W	226	188

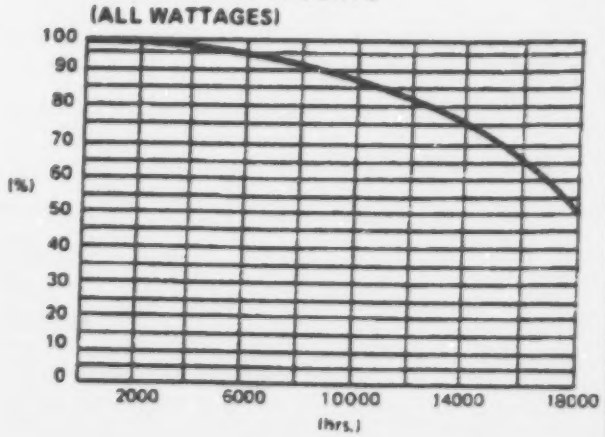
II.

LUMINOUS PERFORMANCE CURVE (ALL WATTAGES)



III. This curve applies when the lamps are used under normal operating conditions with a reactance ballast and in a horizontal burning position.

LAMP MORTALITY CURVE (ALL WATTAGES)



IV.

Figure 5.3.23 Operating Characteristics of Typical Low Pressure Sodium Lamps

5.3.6 Colour and Colour Rendering

1. Colour Selection Guide

The colour and reflectances of coloured surfaces are important issues to the amount of light seen by the eye and the psychological perception elicited. Note the following:

- for areas with low illumination levels (100–500 lux), colours should be selected to have low reflectance (15–35%);
- for areas with high illumination levels (500–1000 lux), colours should be selected to have high reflectance;
- small rooms may require light colours to provide a more spacious visual sensation while maintaining relatively high values of illuminance; large rooms are not much affected by wall colour scheme and reflectances.

Figure 5.3.24 shows the efficiency of inter-reflection of various coloured walls.

For more information on colour scheme and selection see IESNA Reference Volume, 1984, Chapter 5.

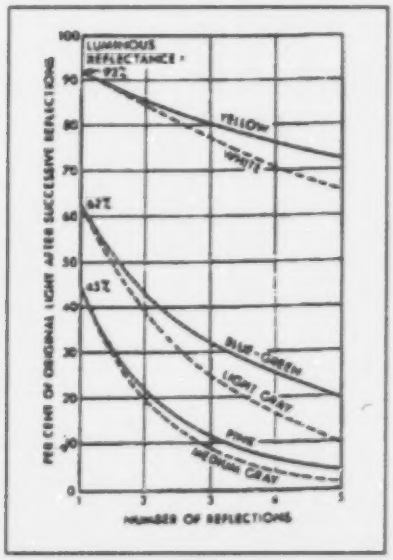


Figure 5.3.24 Comparison of interreflection efficiencies of colored and neutral surfaces having the same luminous reflectance.

Required Quality	Minimum Colour-Rendering Index (Ra)	Recommended Colour Temperature (K)	Examples of Rooms
As High as Possible	85	6500–7400 approx. 4000	Colour Judging, Matching Photography Printing, handling of artifacts, medical examinations
Good	70	Approx. 4000	Typical offices; storerooms and workshops where sorting by colour is important
Medium	40	—	Corridors, staircases, storerooms outdoor lighting where colour rendering is of little importance
None	40	—	Mechanical/electrical rooms, dead storage, outdoor lighting

Table 5.3.6 Recommended Range of CRI

5.3.6 Colour and Colour Rendering (cont'd)

2. Light Source Colour Rendering

Colour rendering of light sources is based on the CIE Colour Rendering Index (CRI) criteria. Refer to IES Reference Volume, Chapter 5, 1984 for specific information. Table 5.3.7 lists the CRI of common light sources, while Table 5.3.6 lists ranges of acceptable CRI indices in relation to space use.

Test Lamp Designation	CIE Chromacity Coordinates		Correlated Colour Temperature	CIE General Colour Rendering Index
	x	y	(Kelvins)	(Ra)
Fluorescent Lamps				
Warm White	.436	.406	3020	52
Warm White Deluxe	.440	.403	2940	73
White	.410	.398	3450	57
Cool White	.373	.385	4250	62
Cool White Deluxe	.376	.374	4050	89
Daylight	.316	.354	6250	74
Three–Component A	.376	.374	4100	83
Three–Component B	.370	.381	4310	82
Three–Component C	.448	.408	2857	80
Simulated D50	.342	.359	5150	95
Simulated D55	.333	.352	5480	98
Simulated D65	.313	.325	6520	91
Simulated D70	.307	.314	6980	93
Simulated D75	.299	.315	7500	93
Mercury, clear	.326	.390	5710	15
Mercury, improved colour	.373	.415	4430	32
Metal Halide, clear	.396	.390	3720	60
Xenon, high pressure arc	.324	.324	5920	94
High Pressure Sodium	.519	.418	2100	21
Low Pressure Sodium	.569	.421	1740	–44
DXW Tungsten Halogen	.424	.399	3190	100

Table 5.3.7 Colour and Colour Rendering Characteristics of Common Light Sources

5.4 ILLUMINANCE AND LUMINANCE SURVEYS

5.4.1 Field Measurements

General

Field measurements are conducted in order to obtain data on building lighting systems performance. It is important to realize that all measurements are affected by the nature of the space in which they are taken. It is therefore mandatory that a complete and accurate record of the characteristics of the space and of the luminaires in it be kept. Attention should be given to the following:

- lamp type, age and burning position;
- lens type and their visible deterioration;
- ballast type and ratings;
- stability and quality of voltage supply;
- maintenance conditions of luminaire;
- ambient operative temperature for the luminaire;
- reflectance of all significant surfaces;
- furniture layout and obstructions (such as trees, and buildings, for exterior lighting);
- mounting arrangement, leveling and aiming (if required).

It is important to decide which measurements need to be taken and ensure that the lighting equipment and HVAC equipment are in normal and stable operating conditions. This means that it is best to take measurements during working hours, or after working hours provided that the pertinent HVAC and lighting systems are left operating normally. Fluorescent, high intensity discharge (HID) and low pressure sodium (LPS) lamps require at least one hour to reach thermal and photometric stability, while incandescent lamps only require 20 minutes. All lamps must be properly aged before any testing can be undertaken. With the exception of incandescent lamps, which require at least 20 hours, all others should be aged at least 100 hours.

Most instruments require that their photocell be exposed to the ambient light for about five minutes and operated at specified ambient temperature ranges prior to making any measurements. All meters require proper handling and regular calibration (normally once a year). The manufacturer should be consulted to ensure that the proper level of care is maintained in the use of its equipment.

Meter accuracy of $\pm$ 10% is generally acceptable as the maximum level of permissible error. However care must be taken to use the appropriate correcting factors for light sources, (as provided by the manufacturer) and for recalibrated scales. Errors may vary considerably from one end of the meter's CIE spectral sensitivity response curve to the other, and this should be considered. Naturally all meters should have photocells suitably colour and cosine corrected, otherwise appropriate corrections, as recommended by the manufacturer, must be applied. Each manufacturer specifies the operating characteristics of its instruments and it should be consulted.

5.4.2. Electrical Lighting Surveys For Indoor Applications

Stage I. Measurement of Illuminance for General Areas

Instrument: illuminance meter; list name, type, model and calibration details.

The following steps are recommended:

a. energize and stabilize both thermally and photomatically the lighting installation and the meter;

b. divide each area to be measured into equal sub-areas of square size (as near as possible), using the following table to determine the number of squares needed:

Room Index	Number of Points
Below 1	4
1 and below 2	9
2 and below 3	16
3 and above	25

$$\text{Room Index} = \frac{W \times L}{H(W+L)}$$

W = Room width
L = Room length
H = Height above desk (desk assumed to be 760 mm high) to bottom of luminaire

Limitations

- Valid for luminaire spacing to mounting height ratio of 1.5:1
- accuracy of ± 10%; for an accuracy of ± 5%, double the number of points
- valid if measurement grid does not coincide with luminaire grid. If it does, add more points to compensate (i.e. those on cross points of the grid)

c. measure the illumination at the center of the square, excluding body shadows, unless a point represents exactly the position and orientation of an occupant at work in which case body shadows may be included;

d. average all points.

Stage I. Measurement of Illuminance for Task Areas

Instrument: illuminance meter; list name, type, model and calibration details

The following steps are recommended:

a. energize and stabilize both thermally and photomatically the lighting installation and the meter;

b. check that worker is at his normal working position;

c. place the photocell on the plane of work where the visual task is performed (horizontal, vertical or inclined); do not eliminate the shadows which are normally found as part of the workstation; eliminate daylighting contribution;

d. measure illumination at multiple points on the area(s) containing the common visual task(s) and complete Table 5.4.1. See Figure 5.4.1 for desk work measuring targets; for other cases measuring grid should allow for a minimum of four points;

e. calculate average illumination and check for compliance with applicable codes and standards (see Appendix 5.2).

Work Point	Description of Work Point	Height above Floor (m)	Plane (0°, 90°)	Illuminance (lux)		Observations
				Total	General	
1– max 2– min 3– 4– 5– 6–						
Avg.						

Table 5.4.1 Table for STAGE I Task Illuminance Survey

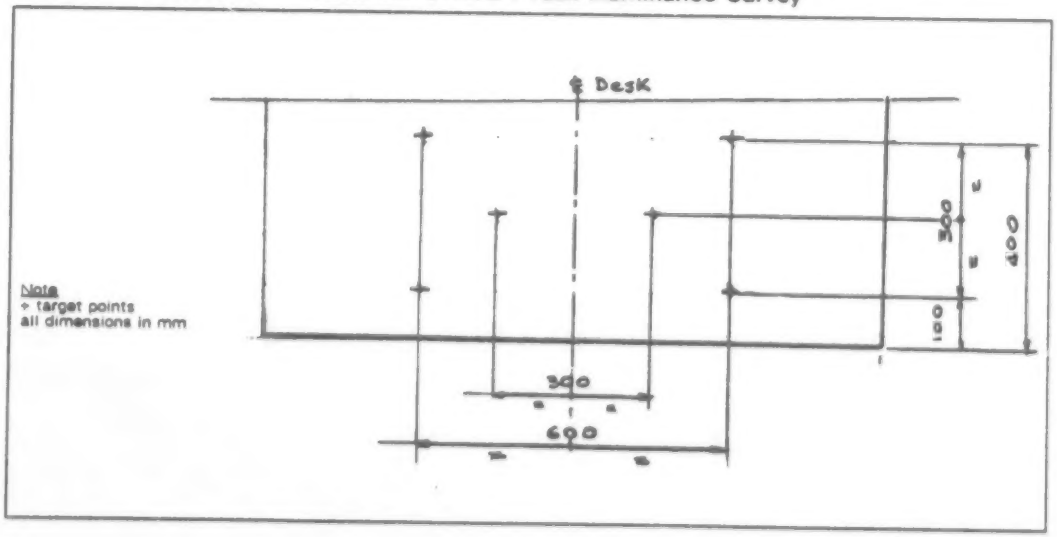


Figure 5.4.1 Measuring points for STAGE I Task Illuminance Survey

Stage II and III. Measurement of Illuminance for General Areas

Instrument: illuminance meter; list name, type, model and calibration details

The following steps are recommended:

a. energize and stabilize both thermally and photomatically the lighting installation and the meter;
b. complete the survey form and which follows; reflectance values are obtained using Appendix 5.5.

LIGHTING SURVEY FORM

General Information

Client name and address _____

Local Contact _____

Area Surveyed _____ Date _____ Time _____AM-PM
(code No or description)

Description of Illuminated Area

Type of work performed in area (see instruction 1.)

Length _____m Width _____m Height _____m Room Temp. _____°C

Interior Surfaces	Material	Finish	Colour	% Reflection	Observations
Ceiling Walls Column Partition Floor Shades/Blinds Work surface Equipment					

Table 1. (see instructions 1.-5., p. 88-89)

Description of General Lighting System

Qty.	Total Watts	Light Source	Distribution	Description	Spacing	Mounting	M.H. or Susp.	Physical Condition

Date of installation _____

Approximate hours of use since installation (see instruction 14.)

Rated voltage of luminaires

Full load Voltage (1)_____(2)_____(see instruction 15. & 16.)

Colour of lamps (see instruction 17.)

Table 2. Luminaires (see instructions 6.-13., p. 89)

Description of Supplementary Lighting

Item No.	Work Surface Illuminated	No. of Luminaires	Luminaire Distribution	Lamp Watts & Type	Luminaire Description Location & Mounting	Physical Condition
1						
2						
3						
4						

Further Details (see instructions 24.) _____

_____

Table 2. Supplementary luminaires (see instructions 18.–23, p. 89–90)

Illumination Measurements – Average

(lux on a horizontal plan 76 cm above the floor for general lighting only)

General:

Position the meter's photocell on a horizontal plan 76 cm above the floor. Use a stand or tripod with proper leveling devices.

Exclude daylight during illumination measures, preferably taking readings at night.

Eliminate observer's shading of the photocell.

Select from tables 4 through 9 only the table suited to the area and fill in the lux values required.

Step 1		Step 2		Step 3		Step 4	
Stn.	lux	Stn.	lux	Stn.	lux	Stn.	lux
a–1		b–1		c–1		d–1	
a–2		b–2		c–2		d–2	
a–3		b–3		c–3			
a–4		b–4		c–4			
a–5							
a–6							
a–7							
a–8							
Total							
Average A =		B =		C =		D =	

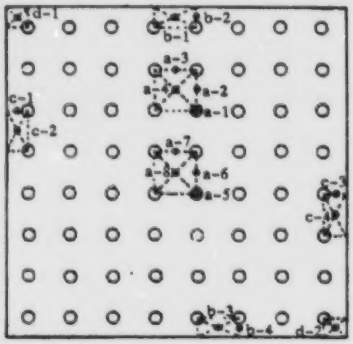


Table 4. Regular Area with Symmetrically Spaced Luminaires in Two or More Rows (see Instruction 25, p. 90)

Step 5. Determine the average illumination by solving the equation:

$$\text{Average illumination} = \frac{A(N-1)(M-1)+B(N-1)+C(M-1)+D}{N\ M}$$

Where: N = number of luminaires per row;
M = number of rows.

= [ ] lux on plane 76 cm above floor (IES Method)

Step 1	
Station	lux
d–1	
d–2	
d–3	
d–4	
Total	
Average D =	

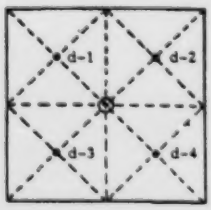
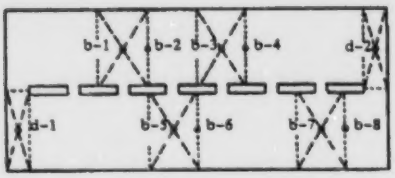


Table 5. Regular area with symmetrically located single luminaire (see instruction 26, p. 90)

Step 2. Average illumination D = [ ] lux on plane 76 cm above floor (IES Method)

Step 1		Step 2	
Station	lux	Station	lux
b–1		d–1	
b–2		d–2	
b–3			
b–4			
b–5			
b–6			
b–7			
b–8			
Total			
Average B =		D =	



Step 3. Determine the average illumination by solving the equation:

$$\text{Average illumination} = \frac{B(N-1) + D}{N}$$

Where:

N = number of luminaires

= ☐ lux on plane 76 cm above floor (IES Method)

Table 6. Regular Area with single row of individual luminaires (see instruction 27, p. 90)

Step 1		Step 2		Step 3		Step 4	
Station	lux	Station	lux	Station	lux	Station	lux
a–1		b–1		c–1		d–1	
a–2		b–2		c–2		d–2	
a–3				c–3			
a–4				c–4			
Total							
Average A =		B =		C =		D =	

Table 7. Regular area with two or more continuous rows of luminaires (see instruction 28, p. 90)

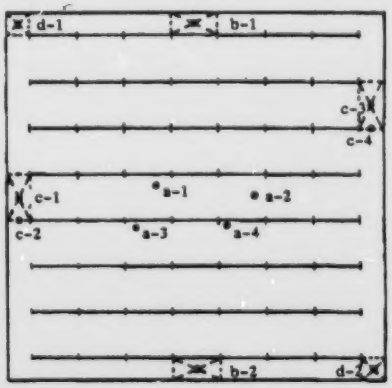
Step 5. Determine the average illumination in areas by solving the equation:

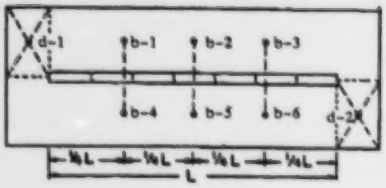
$$\text{Average illumination} = \frac{AN(M-1) + BN + C(M-1) + D}{M(N+1)}$$

Where:

N = number of luminaires per row;
M = number of rows

= ☐ lux on plane 76 cm above floor (IES Method)





Step 1		Step 2	
Station	lux	Station	lux
b–1		d–1	
b–2		d–2	
b–3			
b–4			
b–5			
b–6			
Total			
Average B =		D =	

Step 3. Determine the above average illumination by solving the equation:

$$\text{Average illumination} = \frac{BN+D}{N+1}$$

Where:

N = number of luminaires

= ☐ lux on plane 76 cm above floor (IES Method)

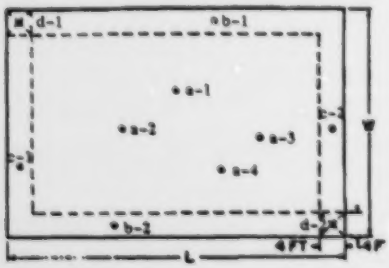
Table 8. Regular area with single row of continuous luminaires (see instruction 29, p. 91)

Step 1		Step 2		Step 3		Step 4	
Station	lux	Station	lux	Station	lux	Station	lux
a–1		b–1		c–1		d–1	
a–2		b–2		c–2		d–2	
a–3							
a–4							
Total							
Average A =		B =		C =		D =	

Table 9. Regular area with luminous or louveral ceiling (see instruction 30, p. 91)

Step 5. Determine the average illumination in areas by solving the equation:

$$\text{Average illumination} = \frac{A(L-8)(W-1) + 8B(L-8) + 8C(W-8) + 64D}{WL}$$



Where:

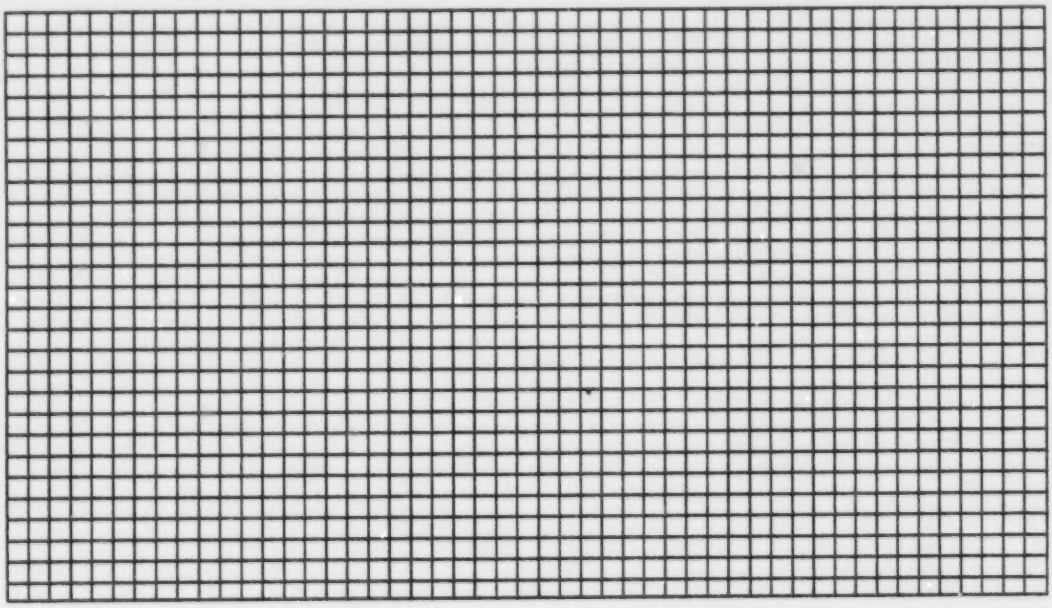
W = Width of the room in feet
L = Length of the room in feet

= ☐ lux on plane 76 cm above floor (IES Method)

INSTRUCTIONS

Sketch of Area

Make a sketch of the area. Show dimensions, including ceiling height in metres and centimetres. Show location of windows and exposure (N,S,E or W). Indicate entrances and chief orientation of occupants, if any. Show obstructions.



Operational Procedure for Use of this Survey Form

1. Type of work performed: Describe the work performed and classify the visual tasks according to Labor Canada COSH Regulations, PWC standard and IES requirements (see Appendix 5.2).

2. **Finish:** Record texture or finish of surfaces as gloss, semigloss, matte.

3. **Colour:** Use the following in describing colours:

Colour		Modifier
Pink	Green	Light
Red	Blue	Dark
Orange	Purple	Medium
Brown	White	
Yellow	Gray	
Tan	Black	
Olive		

4. **Reflectances:** Record in percent. Estimate reflectances of coloured surfaces by value scales (see Appendix 5.5).

5. **Condition:** Record general cleanliness of interior as clean, average or dirty.

6. **Luminaire Wattage:** Record wattage of the individual luminaires. The total wattage of a luminaire is the total wattage of the lamp plus the wattage of the auxiliary equipment (ballast and controls). See Appendix 5.3 for approximate wattage loss of various fluorescent and HID luminaires.

7. **Light Sources:** Record whether the luminaire is: incandescent, quartz–halogen, fluorescent, mercury, metal–halide, high pressure sodium or low pressure sodium.

8. **Distribution Classification:** This to be visually determined. if possible, or obtained from the manufacturer's catalog data. Use the following CIE descriptive table:

Classification	Percent of Total Light Emitted Above Horizontal	Percent of Total Light Emitted Below Horizontal
Direct	0 – 10	100 – 90
Semi–Direct	10 – 40	90 – 60
General Diffuse and Direct–Indirect	40 – 60	60 – 40
Semi–Indirect	60 – 90	40 – 10
Indirect	90 – 100	10 – 0

9. **Luminaire Description:** Give Manufacturer's name, catalog number and any other identification information of the luminaire. Define the luminaire as troffer, suspended, translucent side panels, open top, louvered bottom,etc. Give number, type and description of lamps employed per luminaire; for fluorescent give diameter, and length, and operating current as stated on luminaire ballast.

10. **Luminaire Spacing:** Indicate on the sketch of the area the arrangement and spacing of the luminaires in metres.

11. **Type of Mounting:** Recessed (rec), semi–recessed (semi–rec), surface (surf), suspended (susp).

12. **Mounting Height (MH):** Record metres from floor to bottom of direct or semi–direct luminaires. Record in metres the overall suspension of luminaires other than direct or semi–direct.

13. **Condition:** Record whether lamps are clean, average or dirty, and whether lamps are noticibly blackened.

14. **Hours Used:** Record this figure on the basis of daily usage. Include the use of lighting after regular hours by maintenance personnel or for overtime requirements.

15. **Voltage of Lamps:** Record the rated voltage of luminaires lamps. This is etched on the bulb and is marked on a sticker on the luminaire.

16. **Full Load Voltage:** With the full load on, record one voltage reading near the lighting panel and a second reading farthest from the panel. Consideration should be given to voltage

drops occurring most likely during normal working hours. If the variation in voltage is such as to substantially reduce illumination during working hours, this fact should be noted under "other comments" and given consideration in the final evaluation of the lighting. Record voltage drops below 5% as they reduce lumens output of the luminaire.

17. **Colour of Lamps:** This characteristic is etched on the fluorescent lamp tube. Other colour descriptions are: clear mercury; improved–colour, or deluxe mercury; clear incandescent; daylight incandescent; tinted incandescent; cool white, warm white, daylight; etc.

18. **Item No.:** Assign item numbers to the various types of supplementary luminaires used in the area.

19. **Work Surface Illuminated:** Work surfaces, desks and other equipment on which each type of supplementary luminary is used.

20. **Number of Luminaires:** Give the number of supplementary luminaires of each type used in the area.

21. **Lamp:** Record wattage and type of lamp.

22. **Luminaire Description:** Give manufacturer's name and catalog number if available. Record if lamp is concealed from view of workers.

23. **Condition:** Record whether is clean and in good operating condition.

24. **Further Details:** Record any other details, by item number, which seem important.

25. **Regular Area with Symmetrically Spaced Luminaires in Two or More Rows:** Step 1 in Table 4. Measure and record readings taken at stations a–1, a–2, a–3 and a–4 for typical inner bay. Measure and record readings taken at stations a–5, a–6, a–7 and a–8 for a typical centrally located bay. Total and determine average of "a" readings. Call average "A" and record.

    Step 2 in Table 4. Measure and record readings taken at stations b–1, b–2, b–3 and b–4 of typical half bays on each side of the room. Total and determine average of "b" readings. Call average "B" and record.

    Step 3 in Table 4. Measure and record readings taken at stations c–1, c–2, c–3 and c–4 of typical half bays on each end of the room. Total and determine average of "c" readings. Call average "C" and record.

    Step 4 in Table 4. Measure and record readings taken at stations d–1 and d–2 for two typical corner quarter bays. Total and determine average of "d" readings. Call average "D" and record.

26. **Regular Area with Symmetrically Located Single Luminaire:** Step 1 in Table 5. Measure and record readings taken at station d–1, d–2, d–3 and d–4 for all four quarter bays. Total and determine average of "d" readings. Call average "D" and record.

27. **Regular Area with a Single Row of Individual Luminaires:** Step 1 in Table 6. Measure and record readings taken at stations b–1 through b–8 for four typical half bays located two on each side of the area. Total and determine average of "b" readings. Call average "B" and record.

Step 2 in Table 6. Measure and record readings taken at stations d–1 and d–2 for two typical corner quarter bays. Total and determine average of "d" readings. Call average "D" and record.

28. **Regular Area with Two or More Continuous Rows of Luminaires:** Step 1 in Table 7. Measure and record readings taken at stations a–1, a–2, a–3 and a–4 located near the center of the area. Total and determine average of "a" readings. Call average "A" and record.

Step 2 in Table 7. Measure and record readings taken at stations b–1 and b–2 located at each mid–side of the room and midway between the outside row of luminaires and the wall. Total and determine average of "b" readings. Call average "B" and record.

Step 3 in Table 7. Measure and record readings taken at stations c–1, c–2, c–3 and c–4 at each end of the room. Total and determine average of "c" readings. Call average "C" and record.

Step 4 in Table 7. Measure and record readings taken at stations d–1 and d–2 in two typical corners. Total and determine average of "d" readings. Call average "D" and record.

29. **Regular Area with a Single Row of Continuous Luminaires:** Step 1 in Table 8. Measure and record readings taken at stations b–1 through b–6. Total and determine average of "b" readings. Call average "B" and record.

Step 2 in Table 8. Measure and record readings taken at stations d–1 and d–2 in typical corners. Total and determine average of "d" readings. Call average "D" and record.

30. **Regular Area with a Luminous or Louveral Ceiling:** Step 1 in Table 9. Measure and record readings taken at stations a–1, a–2, a–3 and a–4 located at random in the central portion of the room. Total and determine average of "a" readings. Call average "A" and record.

Step 2 in Table 9. Measure and record readings taken at stations c–1 and c–2 located 60 cm from the short walls at random lengthwise of the room. Total and determine average of "c" readings. Call average "C" and record.

Step 3 in Table 9. Measure and record readings taken at stations c–1 and c–2 located 60 cm from the short walls at random width wise of the room. Total and determine average of "c" readings. Call average "C" and record.

Step 4 in Table 9. Measure and record readings taken at stations d–1 and d–2, located at diagonally opposite corners 60 cm from each wall. Total and determine average of "d" readings. Call average "D" and record.

Stage II and III, Measurement of Illuminance for Task Areas

Instrument: illuminance meter, list name, type, model and calibration details

The following steps are recommended:

a. energize and stabilize both thermally and photomatically the lighting installation and the meter;

b. check that worker is at his normal working position;

c. place the photocell on the plane of work where the visual task is performed (horizontal, vertical or inclined); do not eliminate the shadows which are normally found as part of the workstation; eliminate daylighting contribution;

d. refer to grid figure below, center measuring grid on the common work surface area and take illumination levels at each point. It is convenient to generate a permanent surveying template on a transparent mylar film (use coordinates of Table 5.4.2);

e. calculate average illumination and check for compliance.

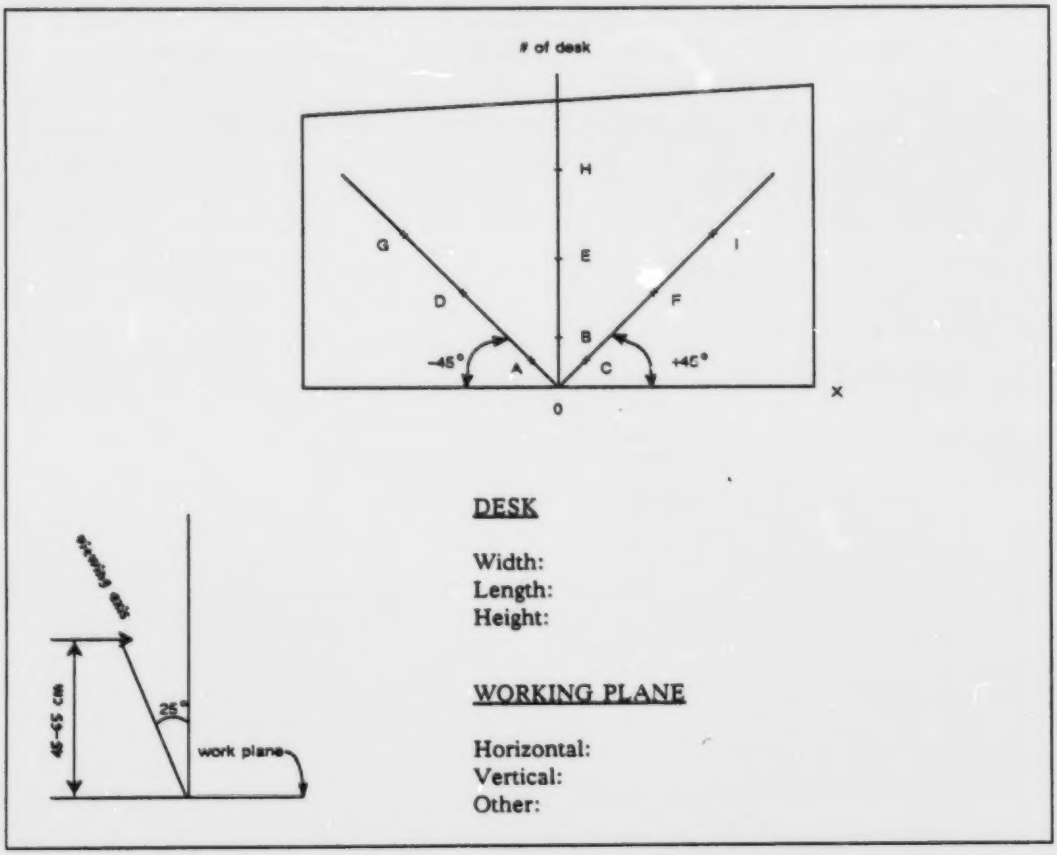


Figure 5.4.2 Measuring Points for Stage II and III Task Illuminance Survey

Point	Illuminance (lux)		Observations
	General Lighting	Task Only	
A			
B			
C			
D			
E			
F			
G			
H			
I			
Average			
Total Average			

Point	Coordinates (mm)	
	X	Y
A	−160	25
B	0	35
C	160	25
D	−130	130
E	0	190
F	130	130
G	−470	280
H	0	400
I	470	280

Table 5.4.2 Stage II, III Task Illuminance Survey

Stage I. Measurements of Luminance

Instruments: 1° luminance meter, list name, type, model and calibration details

The following steps are recommended:

a. energize and stabilize both thermally and photomatically the lighting installation and the meter;

b. ensure that all lighting loads are energized (task lights also);

c. using a reduced scale floor plan, mark the surfaces of very high perceived luminance or glare;

d. make spot measurements at above identified areas and areas immediately surrounding them, and record values on plane with respect to the viewing position where they were taken;

e. check that ratios between the high luminances and their immediate lower luminances do not exceed 40:1.

Stage II. Measurements of Luminance

Instrument: 1° luminance meter; list name, type, model and calibration details; inclinometer

The following steps are recommended:

a. energize and stabilize both thermally and photomatically the lighting installation and the meter;

b. ensure that all lighting loads are energized (task lights also):

c. identify workstations having apparently common luminance characteristics and workstations of apparently high or low luminance characteristics:

d. referring to Table 5.4.3 and its instructions measure and enter luminances in the field of view of observers located at workstations identified in c. above.

e. check the ratios of task to ambient luminances do not exceed the following ratios:

Task to immediate surroundings	1 to 1/3
Task to remote dark surfaces	1 to 1/10
Task to remote light surfaces	1 to 10
Task to window	1 to 20
Anywhere in the field of view	1 to 40

f. if applicable, answer questions on observation sheet, "General Observation on the Visual Environment."

Location	Brightness in cd/m²					
	A	B	C	D	E	F
Luminaire at 45° above eye level						
Luminaire at 30° above eye level						
Luminaire at 15° above eye level						
Ceiling, above luminaire						
Upper wall or ceiling next to luminaire						
Upper wall between two luminaires						
Wall at eye level						
Column						
Floor						
Shades or blinds						
Windows						
Task						
Immediate surroundings of task						
Peripheral surroundings of task						
Highest brightness in field of view						

Table 5.4.3 Ambient Luminance Measurements (see instruction 1)

Description of highest luminance:

General Observation on the Visual Environment (see instruction 2)*

Percentage of workers who are subject to undue direct glare from:

General lighting system _____

Supplementary lighting _____

Daylighting _____

If there are adjustable daylight control means, are they being used as effectively as possible to minimize glare? _____

What percentage of workers are subject to troublesome shadows at work points? _____

What is your opinion of the general lighting system? (good, fair, poor) _____

What is your opinion of the supplementary lighting system? (good, fair, poor) _____

Rate the room as a whole from the standpoint of pleasantness and visual comfort of the workers (good, fair, poor) _____

Changes requested to affect the improvement of the visual environment _____

_____

Other comments? _____

_____

*To be answered by a competent professional, skilled in the art and science of lighting

Instructions

1. Take the worker's position at Work Point A. Locate Point A and the direction of view by an arrow and a letter on the sketch. Aim the instrument at the brightest area of a luminaire which occurs at about 45° above eye level in the direction the worker faces. Balance the luminance of the instrument fields. Record the reading in cd/m².

   Remaining in the same position, repeat this operation on a luminaire which occurs at about 15° above eye level. Record this reading.

   Remaining in the same position, take a reading at a point on the ceiling just above a nearby luminaire. Record this reading.

   Remaining in the same position, take a reading at a point on the ceiling midway between two nearby luminaires. Record this reading.

Remaining in the same position, take a reading of the ceiling or upper wall at a point apparently immediately adjacent to the luminaire at 15° above eye level previously measured.

Remaining in the same position at location A, proceed with the remaining measurements itemized in Table 5.4.3. Record all of these readings.

If there are window shades, draw them and read the brightness of the window glass or of the visible scene seen through it. This will indicate possible worst–case conditions.

Task – the work itself, paper or other material to be worked on.

Immediate surroundings – the pad, desk top, or other surface immediately adjacent to the work within a 60° cone seen by the worker when working on the task.

Peripheral surroundings – the surroundings outside the 60° cone seen by the worker when working on the task.

Select, by visual inspection, the highest luminance in the entire field of view of the worker. Measure and record it along with a brief description of its value and location with respect to the worker's field of view.

Describe source of highest luminance as: general lighting luminaire, local lighting luminaire, window, etc.; so many degrees to right or left, so many degrees above horizontal.

Assume, successively, the other locations B through F, taking as many of these positions as may be required to obtain a representative survey of the luminance distribution. Repeat all measurements and recordings outlined above, include showing locations and orientations on sketch.

2. All lighting in the area, both general and supplementary, should be in normal use. Assume successively the worker's positions A through F in table 5.4.3 and record your personal reactions to the various conditions experienced. Remain in at least three of these positions for several minutes before recording your impression. Assume the worker's role as closely as possible. Imitate as far as feasible the visual habits of the worker (i.e., looking intently at the work for one or two minutes, momentarily glancing up from time to time and then again attentively regarding the work point).

Stage III, Measurements of Luminance

Instrument: 1° luminance meter, adapter lenses, tripod, inclinometer, Polaroid instant camera; list name, type, model and calibration details of instrument

This stage requires more detailed measurements then those conducted under Stage II. Follow the same steps as for Stage II. In addition, target surveys for all significant surfaces of very bright or very dark nature which are in any portion of the field of view of the observer. Extreme daylight contributions are also investigated.

Luminance of tasks, backgrounds and surrounding areas are taken and values compared with maximum ratios in step e. in Stage II Measurements of Luminance.

For the selected workstation, an instant photograph is taken with the room lights on and from the usual working position for that station. The field of view should include any source of daylight which is normally viewed from that position as well as the work surfaces and

surround. Where glare problems have been identified, a series of photographs may be necessary in order to include all surfaces to be measured.

The luminance photometer is then used from the same position to measure luminance values for a range of sources and surfaces. These values are marked directly onto the photographs with a fine–point marker.

Typical points for luminance measurement will include: visible sky, outside objects, window frames, walls, ceilings, floors and work surfaces.

This procedure may be repeated with the lights off in order to assess the contribution that interior lighting may be making to the reduction of glare, and at night, in order to assess the contribution that daylighting makes with respect to ambient luminances.

5.4.3 Electrical Lighting Surveys for Exterior Applications

General

Most of the concepts described earlier in section 5.4.1 apply here. However the following additions must be considered:

- ensure the exclusion of extraneous lighting from surrounding areas;
- realize that overcast skies affect readings;
- snow conditions can introduce appreciable luminance and illuminance changes;
- operator's shadow can prove to be more of a problem;
- operator's light coloured clothing can have a greater influence on readings;
- extreme operating conditions require appropriate temperature corrections and meter handling precautions;
- the photocell of the meter should be capable of being levelled for horizontal illumination measurements;

Note: It is sometimes desirable to take measurements which include some of the above problems to gauge the effect they might have on illumination intensity and distribution.

Stage I and II, Measurements of Illuminance for Access Roads, Parking Areas and Entrances

Instrument: low level illuminance meter, list name, type, model, and calibration details

Buildings and building complexes are often served by private access roads leading to parking lots and entrance ways.

The following steps are recommended:

a. use a properly scaled site map on which measuring stations can be identified;

b. access roadways and lanes are divided into equal sections of at least three metres in width, ending at the luminaire center line; parking areas are divided into two areas: the first one is the access/exit and is treated as an access roadway, the second is the parking zone, normally five metres deep, in which case the center of it is used to locate measuring stations; entrance ways are divided in equal three metre squares; see Figure 5.4.3 as an example;

c. at least three luminaires of equal characteristics and spacings must be considered; different spacing, luminaire types, lamp types or mounting arrangements require additional measuring stations;

d. the center of each square is selected as a measuring station; in addition, points opposite to luminaires and half-way in between are selected to represent possible maximum or minimum lighting levels; at curves, identify a station immediately before, after and at the center of it;

e. the sensor of each station is placed horizontal to the road surface and not more than 15 cm above it;

f. when surveying large areas, systematically re–check reference points, to ensure that the meter is still operating correctly (i.e., unaffected by environmental conditions);

g. average illumination levels are obtained for each representative road section by adding the values of readings collected and dividing it by the number of readings; minimum and maximum levels are also identified;

h. check the Tables 5.4.4 and 5.4.5 for compliance;

i. prepare a test report which indicates the following:

- location;
- date, time and weather conditions;
- description of installation and lighting equipment (inclusive of lamp and ballast type and mounting arrangements);
- actual mounting height, spacing, and special circumstances for surrounding conditions, extraneous light sources, etc.;– diagram showing test stations with reference dimensions;
- electrical operating conditions;
- condition of luminaires and operation time in hours;
- tabulation of test data;
- ratio of average to minimum, maximum to minimum and average levels of illumination;
- description of instrument used and manner of use.

NOTE: Facade lighting surveys are rather cumbersome and outside the scope of this document. Use computer calculations with a few field check points to verify appropriateness of lighting. Refer to IESNA Section 12, Application Volume 1987 and Section 9, Reference Volume 1984 for specific information.

Open Parking					
Level of activity	For vehicular traffic		For pedestrian safety	For pedestrian security	
	Lux	Unif. Ratio	Lux	Lux	Unif. Ratio
Low	5	4:1	2	9	5:1
Medium	10	3:1	5	20	5:1
High	20	3:1	10	40	5:1

	Covered Parking	
	Lux	Unif. Ratio
Parking and Pedestrian	50	4:1
Ramps and Corners	50	4:1
Entrance Areas	50	4:1

Note: Max/Min ratio not to exceed 10:1 on access/egress routes and 40:1 anywhere else.

Table 5.4.4 Recommended Minimum Illumination Levels for Parking Areas

Area	Illumination level Lux
Sidewalks	10
Walkways	5
Bikeways	10
Pedestrian Tunnels	40
Pedestrian Overpasses	3
Pedestrian Stairways	6

Table 5.4.5 Recommended Minimum Illumination Levels for Pedestrian Ways

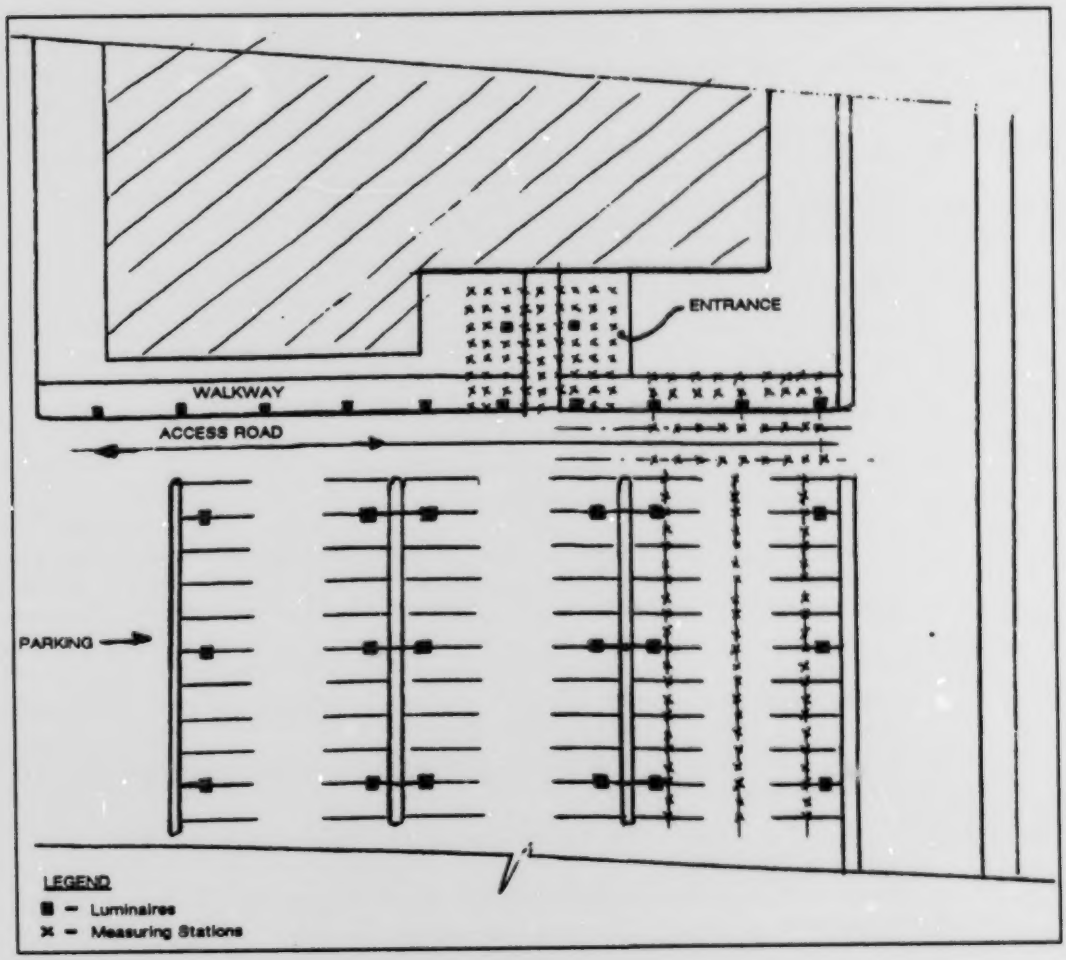


Figure 5.4.3 Parking Facilities Surveying Grid

Stage III, Measurements of Illuminance for Access Roads, Parking Areas and Entrances

This stage would normally require that extensive surveys be taken at vertical planes as well as horizontal planes. However in generic government facilities this information is rarely required and it is therefore not treated in this document. For more information on this subject contact PWC, HQ, Architectural and Engineering Branch.

5.5 REFLECTANCE AND TRANSMITTANCE SURVEYS

It is important to note that the methodologies for Stage I and Stage II assume that surfaces reflect as ideal Lambertian reflectors, that is, they are perfectly diffuse and transmit with no absorption. In reality, both reflectance and transmittance behave differently, however the error introduced, considering typical office environments, is quite small and acceptable, in view of the great simplifications it can afford. Table 5.5.3 lists reflectance and transmittance properties of common materials.

STAGE I, MEASUREMENT OF REFLECTANCE

Instrument: Calibrated colour chips, (available from major paint companies) or illuminance meter

There are basically two methods available:

a. using comparative calibrated colour chips or;
b. using an illuminance meter.

The use of method a. consists of visually matching pre–calibrated colour chips to the surface to be tested. Errors can be in excess of 20% since reliance is given to the ability of the operator to make a valid colour match. The use of method b. consists of placing the measuring photocell of the illuminance meter on the test surface to measure incident light, then placing the photocell 5–7 cm away, facing the test surface to measure the reflected light. Care must be exercised to eliminate shadows and keep the measuring plane of the photocell parallel to the plane of the test surface. The reflectance, in percent, is calculated by dividing the incident light reading by the reflected light reading and multiplying the result by 100.

$$R(\%) = \frac{\text{incident light}}{\text{reflected light}} \times 100$$

Figure 5.5.1 graphically explains the concept.

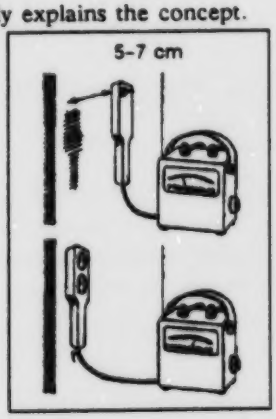


Figure 5.5.1 Reflectance Measurement (Using an illuminance meter)

The following steps for field surveys are suggested:

a. if illuminance meter is used, stabilize it by exposing its photocell to ambient light for five minutes;
b. select a representative area for the major ambient surfaces and for the common work surfaces (i.e., walls, ceilings, floors, desks);
c. make the colour match or use the meter to read the value of the reflectance;
d. repeat for unusually dark or bright surfaces which are located in the observer's field of view;
e. check values against Table 5.5.1.

Ceiling	about	80%
Walls	40 –	70%
Partitions	40 –	70%
Floors	20 –	30%
Furniture	25 –	45%
Equipment	25 –	45%
Drapes	40 –	60%

Table 5.5.1 Recommended Average Room Reflectance Values

STAGE II. MEASUREMENTS OF REFLECTANCE

Instrument: Calibrated colour chart, or luminance meter.

The following steps are recommended:

a. if luminance meter is used, stabilize it by exposing its photocell to ambient light for five minutes;
b. place the calibrated colour chart on the surface to be measured;
c. make a visual match between the calibrated colour chart and the test area;
d. measure the calibrated luminance on the calibrated colour chart and the test area, ensuring that both occupy the same physical area;
e. calculate the reflectance by solving the equation below:

$$R(\%) = \frac{\text{luminance of test area}}{\text{luminance of colour chart}} \times \text{reflectance of colour chart}$$

f. repeat this process for all major ambient and task surface areas, averaging where necessary as follows:

Average

$$R(\%) = \frac{\text{Area}_1 \times R_1 + \text{Area}_2 \times R_2 + \ldots + \text{Area}_N \times R_N}{\text{Area}_1 + \text{Area}_2 + \ldots + \text{Area}_N}$$

g. check values against Table 5.5.1, Stage I.

STAGE III. MEASUREMENT OF REFLECTANCE

Instrument: reflectometer

This stage is recommended for those cases where precise information is needed for unusual reflective surfaces affecting the luminous environment and behaving very differently from Lambertian surfaces.

Since reflectometers are normally available only in laboratories, it is suggested that a sample of the material to be measured be sent to an independent testing illumination laboratory for proper analysis (see Appendix 5.15 for a list of such laboratories).

STAGE I. MEASUREMENT OF TRANSMITTANCE

Instruments: illuminance meter

Materials: glazing specifications and drape specifications

Follow these steps:

a. From architectural drawings and specifications, extract the transmittance values for the various glazings used in the building. Refer to Table 5.5.2 for an estimation of window dirt depreciation, choose one value and multiply it by the transmittance of the glass to obtain average in-service transmittance;

b. for drape materials aim the photocell at the inside surface, take several measurements and calculate an average value. Aim the photocell at the same spots but with drapes excluded and measure the amount of incoming flux. The ratio of the two values multiplied by 100 gives the transmittance, in percent, of the draping material. Glazing materials, where possible, can also be tested using the same principle (i.e., closed and then opened windows);

c. the total transmittance values are usually in the 40–60% range for window areas, to allow for proper daylighting penetration and control. Tasks very susceptible to glare may require stricter values.

Vertical Glazing	Clean interior conditions	Dirty interior conditions
Clean exterior location	0.9	0.7
Industrial location	0.9	0.6
Very dirty location	0.7	0.5

Table 5.5.2 Glazing Dirt Maintenance Indices

STAGE II, MEASUREMENT OF TRANSMITTANCE

Instruments: luminance meter (20° cell or larger is preferred)

Glazing materials are covered in Stage I. For draping materials follow these steps:

a. stabilize luminance meter by exposing its photocell to ambient illumination;
b. select areas which use representative window draping materials. Draping materials also include perforated vertical Venetian blinds, solar drapes, and solar film sheets which are not bound on glazing materials;
c. from typical workstations aim the meter to the draping material covering the window and record the luminance level. Immediately afterwards remove the drapery and measure the luminance of the window at the same point and plane. If drapery is uneven several readings must be taken and averaged;
d. calculate the transmittance in percent by dividing the first reading by the second reading and multiplying the result by 100;
e. the total transmittance values are generally 40–60% for typical situations, but may be reduced to much lower levels for very sensitive tasks.

STAGE III, MEASUREMENT OF TRANSMITTANCE

Instrument: reflectometer

This stage is recommended for cases where specialized transmittance characteristics have to be checked (i.e., lenses, special glazings and films). UV lens deterioration (yellowing) is also part of this stage.

Because the instrumentation and measurement techniques are highly specialized it is recommended that an independent lighting testing laboratory be contacted to do this work. (See Appendix 5.15 for a list of such laboratories.)

Material	Reflectance* or Transmittance# (%)	Characteristics
	REFLECTING	
Specular		
Mirrored and optical coated glass	80 to 99	Provide directional control of light and brightness at specific viewing angles. Effective as efficient reflectors and for special decorative lighting effects.
Metallized and optical coated plastic	75 to 97	
Processed anodized and optical coated aluminum	60 to 70	
Chronium	60 to 65	
Stainless steel	55 to 65	
Black structural glass	5	
Spread		
Processed aluminum (diffuse)	70 to 80	General diffuse reflection with a high specular surface reflection of from 5 to 10 per cent of the light.
Etched aluminum	70 to 85	
Satin chronium	50 to 55	
Brushed aluminum	55 to 58	
Aluminum paint	60 to 70	
Diffuse		
White plaster	90 to 92	Diffuse reflection results in uniform surface brightness at all viewing angles. Materials of this type are good reflecting backgrounds for coves and luminous forms.
White paint**	75 to 90	
Porcelain enamel**	65 to 90	
White terra–cotta**	65 to 80	
White structural glass	75 to 80	
Limestone	35 to 65	
	TRANSMITTING	
Glass		
Clear and optical coated	80 to 99	Low absorption; no diffusion; high concentrated transmission. Used as protective cover plates for concealed light sources.
Configurated, obscure, etched, ground, sandblasted and frosted	70 to 85	Low absorption; high transmission; poor diffusion. Use only when backed by good diffusing glass or when light sources are placed at edges of panel to light the background.

* Specular and diffuse reflectance

** These provide compound diffuse–specular reflection unless matte finished

\# In as much as the amount of light transmitted depends upon the thickness of the material and angle of incidence of light, the figures given are based on thickness generally used in lighting applications and on near normal angles of incidence.

Table 5.5.3 Reflecting and Transmitting Materials (published by courtesy of IESNA)

Material	Reflectance* or Transmittance# (%)	Characteristics
	TRANSMITTING	
Opalescent and alabaster	55 to 80	Lower transmission than above glasses; fair diffusion. Used for favourable appearance when indirectly lighted.
Flashed (cased) opal	30 to 65	Low absorption; excellent diffusion. Used for panels of uniform brightness with good efficiency.
Solid opal glass	15 to 40	Higher absorption than flashed opal glass; excellent diffusion. Used in place of flashed opal where a white appearance is required.
Plastics		
Clear prismatic lens	70 to 92	Low absorption; no diffusion; high concentrated diffusion. Used as shedding for fluorescent luminaires. outdoor signs and luminaires.
White	30 to 70	High absorption; excellent diffusion. Used to diffuse lamp images and to provide even appearance in lamp images and to provide even appearance in fluorescent luminaires.
Colours	0 to 90	Available in any colour for special colour rendering lighting requirements for esthetic reasons.

* Specular and diffuse reflectance

** These provide compound diffuse–specular reflection unless matte finished

\# In as much as the amount of light transmitted depends upon the thickness of the material and angle of incidence of light, the figures given are based on thickness generally used in lighting applications and on near normal angles of incidence.

Table 5.5.3 Reflecting and Transmitting Materials (published by courtesy of IESNA) (cont'd)

Material	Reflectance* or Transmittance# (%)	Characteristics
	TRANSMITTING	
Marble (impregnated)	5 to 30	High absorption: excellent diffusion; used for panels of low brightness. Seldom used in producing general illumination because of the low efficiency.
Alabaster	20 to 50	High absorption: good diffusion. Used for favourable appearance when directly lighted.

* Specular and diffuse reflectance
** These provide compound diffuse–specular reflection unless matte finished
\# In as much as the amount of light transmitted depends upon the thickness of the material and angle of incidence of light, the figures given are based on thickness generally used in lighting applications and on near normal angles of incidence.

Table 5.5.3 Reflecting and Transmitting Materials (published by courtesy of IESNA) (cont'd)

5.6 LUMINAIRE ENVIRONMENTAL AND OPERATIONAL SURVEYS

INTRODUCTION

The technical and economic performance of any lighting system depends on its electrical, thermal and operational characteristics being as near as possible to design conditions. A lighting system is often incapable of performing to capacity because it is operating outside recommended ranges.

Surveys should be designed to collect all information relevant to environmental and operational issues. The following paragraphs group common characteristics under simple headlines. There is only one stage of diagnostics as it is suggested that all issues discussed here be analyzed routinely.

ELECTRICAL PARAMETERS

Instrument: electrical multimeter

Electrical parameters for operational requirements of lamps and ballasts are provided by ANSI Standards C82.1(1985), C82.2(1984), C82.5(1983), C82.6(1981) and C82.9(1981).

Some light sources and control components, such as PL and Quadraplex fluorescent compact lamps, and electronic ballasts, do not have standard specification requirements. In these cases it is recommended that the manufacturer of each component be contacted to provide complete specifications and operating information in conjunction with other components of the luminaire (i.e., interaction between lamps, ballast, reflector, and control gear).

Generally the following points require specific operational information:

- supply voltage/current, d.c. or a.c., with acceptable wave shape and tolerances;
- voltage variation not exceeding 2%;
- frequency of power supply and tolerances;
- power output and power regulation with operational ranges;
- maximum voltage/current crest factor;
- maximum acceptable level of harmonics;
- voltage and voltage regulation of cathodes, where applicable;
- current and current regulation of cathodes, where applicable;
- wiring requirements, such as oversizing, and separate grounding;
- type and limitations of ballasts to be used;
- type and limitations of controls to be used.

Caution must be exercised when examining energy efficient retrofits. In this case consult the original electrical specifications and determine if the retrofitted luminaire complies with them. Quite often this might not be the case for the correct electrical, thermal and fire safety operation. Non-compliance with the original component's specification may void its warranty.

MECHANICAL PARAMETERS

Under this heading, installed luminaires are evaluated, considering structural strength, mounting strength and impact on the building HVAC system.

Structural Strength

Field checks of luminaire rigidity and structural strength is usually a visual inspection. Problems exist when the inspection reveals deflections of materials exceeding 12 mm. This includes T–bar ceilings, framed lenses and lay–in lenses. Vibration problems are addressed by the use of suitably designed shock absorbing devices. These must be checked. Luminaire enclosures are checked to ensure there is no light leakage, and, for weather proof types, that there is a suitable weather resistant gasket. Check that tamper proof fastening is available where required, such as high mast installations, and security areas.

Mounting Strength

Identify that mounting methods are adequate for the size and weight of the luminaire. Large fluorescent units and many large HID units often require gripping sockets and specially designed structural hanging devices.

Outdoor luminaires are often subject to the stress of the elements and their mounting hardware should be checked for visible signs of mechanical stress. Also winches and other built–in mechanisms should be checked for signs of wear and for suitability to actual maintenance practices.

Integration with HVAC System

When luminaires are part of the HVAC system, the help of a mechanical engineer is essential. Every luminaire is part of the heat load of the building and as such, handled by the mechanical engineer.

Because the expertise is found in the mechanical discipline, this topic is cross–referenced to that discipline, while the energy issues are cross–referenced to the Energy Performance discipline.

Mechanical Shock

This can be present as a sudden release of mechanical energy or as a sustained level of vibration. Both cases cause various components of the luminaire to fail prematurely.

Better and more appropriate installation techniques and the use of specially designed shock proof lamps offer the best solutions.

ENVIRONMENTAL PARAMETERS

Instrument required: Temperature probe

Ambient Temperature

Ambient temperature affects the operating characteristics of luminaires and most of their components. The most significant effects are registered by the lamp and the ballast. Measure the temperature of the ambient air, the lamp surface and the ballast surface. Note the following guidelines:

a. For best performance of fluorescent lamps ambient temperature are to be about 25°C. HID lamps are affected only slightly by temperature, except for the voltage starting requirements, which increase if the temperature is −25°C or lower;
b. For best performance of fluorescent lamps, lamp temperature is to be about 37°C. HID lamps are less affected by temperature, however they do require that the base does not exceed 210°C and that the outer envelope does not exceed 400°C, to maintain proper component integrity;
c. Ballast case temperature should not exceed 90°C, as for each 10°C increase, the life is halved. Check that plenum temperatures, mounting location and arrangement, and voltage variations do not contribute to increasing the ballast case temperature above 90°C.

A temperature rise of 1.2°C for each 1% increase in voltage supply can be used as a guideline.

Wind Effects

Wind affects the operating temperature of the lamp and as such must be considered. Wind can also impose a significant mechanical load on the luminaire and this aspect must also be considered.

Gather wind information utilizing weather data from the local weather office. In addition note the following:

a. cooling wind effects for outdoor fluorescent lamp applications can be counteracted by the use of a slip–on plastic jacket;
b. manufacturers can provide the maximum wind loading acceptable to their luminaire.

Acoustics

Luminaire acoustical performance varies according to the shape, material and mounting arrangements available. Where very low ambient noise levels are required, check that the sound rating is class A (40 dB). More stringent requirements call for remote mounting of ballasts.

Basic acoustics measurements are described in the D08: Acoustic Environment Evaluation.

Miscellaneous Effects

There are many other environmental conditions affecting the performance and operation of luminaires. This is to alert the reader about the most common, including: yellowing and brittleness caused to plastics by ultraviolet energy from the sun and lamps; thermal shock; extreme humidity conditions; excessive airborne pollutants; and corrosive atmospheric conditions.

OPTICAL PROPERTIES

Introduction

The optical properties of luminaires are responsible for the delivery of the luminous flux at a surface. Physical surveys of these properties examine a limited number of issues, while detailed optical analyses are left to specialized lighting laboratories.

Reflector

This is normally a metal piece which surrounds the light source and is intended to direct the generated luminous flux in specific ways by means of reflection techniques. Table 5.6.1 shows properties of finishes for common materials used in luminaires and can be used as a guide to compare installed luminaires.

The following information is collected for each type of reflector:

a. installation year;
b. make and model;
c. material, finish and reflectance;
d. level of cleaning maintenance;
e. visible deterioration (scratches, pitting, yellowing).

This data is compared with original specifications or renovation technical information to ensure:

- the installation conforms to engineering specifications;
- renovations used materials conforming to the technical performance intent of the design and use of space;
- the reflectance degradation does not exceed 10% of the original value.

Corrective recommendations are given after data evaluation.

Refractor or Lense

This is the glass or plastic material in front of the light source and precisely directs the luminous flux by transmission control. Plastic lenses are the most common luminaire material in use and Table 5.6.2 describes them in some detail.

Type of Finish	Method of Application*	Principal Uses**	Colours Possible	Character of Reflected Light	Percent Reflectance##	Resistance#				Stability#	Flammability
						Heat	Corrosion	Abrasion	Impact		
Organic coatings											
Lacquers	D,B,S	A,P	Colourless or any colour	Mixed to diffuse	10–90	F	F	P	F	F	Slow burn
Emulsions	D,B,S	A,P	All colours	Mixed to diffuse	10–90	G	G	G	G	G	Slow burn
Enamels	D,B,S	A,P,R	All colours	Mixed to diffuse	10–90	G	G	G	G	G	Slow burn
Baked clear coatings	D,B,S	A,P	Colourless, clear colour	Diffuse to specular	0	G	G	G	G	G	Slow burn
Organisols	D,S	A,P	All colours	Mixed to diffuse	10–90	F	E	G	G	F	None
Ceramic coatings											
Vitreous enamels	D,S	A,P,R	All colours	Diffuse to specular	10–90	E	E	E	P	E	None
Ceramic enamels	D,S,B	A,R	All colours	Mixed to specular	10–90	E	E	E	P	E	None
Metallic coatings											
Chrome plate	Electro-chemical	A,P	Fixed; depending on colour of plated metal	Specular to diffuse	60–88	E	E	E	E	E	None
Nickel plate	Electro-chemical	A,P		Specular to diffuse	55	E	G	E	E	E	None
Cadmium plate	Electro-chemical	P		Specular to diffuse	85	G	G	F	P	E	None
Brass plate	Electro-chemical	A		Specular to diffuse	55–80	P	P	F	P	E	None
Silver plate	Electro-chemical	A,R		Specular	85–95	P	P	F	P	E	None
Laminates	Laminate	A,P,R	All colours of metallic effects	Mixed	10–90	Depends on nature of laminate					Slow burn
Conversion coatings											
Anodized aluminum	Electro-chemical	A,P,R	Natural aluminum (or a wide variety of colours)	Diffuse to specular	60–90	E	E	E	E	E	None
Vacuum metalizing	Vacuum chamber	A,R	Natural aluminum (or a wide variety of colours)	Specular	10–70	Depends on nature of protective coating					None
Vacuum deposition	Vacuum chamber	A,R,T	Colourless to interference effects	Diffuse to specular	0–99	E	E	E	E	E	None

*D – dips, S – spray, B – brush
**A – appearance, P – protection, R – reflectance, T – transmittance
#P – poor, F – fair, G – good, E – excellent
##Depends upon colour.

Table 5.6.1 Properties of Finishes (published by permission of IESNA)

Materials	Common Forms										Reasons for Use and General Data**										
Thermoplastics																					
ABS ##			X				X	X			X	X	HB-V0		X			X	X	NP	60-110
Acetals ##			X				X				X	X	HB		X			X	X	C	80
Acrylics	X		X	X			X	X			X	X	HB				X	X		N	60-90
Acrylic-styrene copolymers			X				X	X			X	X	HB		X	X	X	X		NP-SL	80-95
Cellulose acetates butyrates			X	X	X		X	X				X	HB-V0		X		X	X	X	SL	65-105
Cellulose acetages			X		X		X	X				X	HB		X		X	X	X	NL	60-105
Cellulose propionates			X		X		X	X				X	HB		X		X	X	X	SL	70-105
TFE-fluorocarbons			X		X			X			X		V0		X	X				N	260
Nylons ##			X	X	X		X	X			X		HB-V0		X			X	X	CO	80-150
Polycarbonates ##			X				X				X	X	HB-V0			X		X	X	SL	120
Polyethylenes			X	X	X	X	X	X			X	X	HB-V0	X	X	X		X	X	NP	80-120
Polypropylenes ##			X	X	X		X	X			X	X	HB-V0		X	X		X	X	NP	120-160
Polystyrenes ##	X		X	X	X		X	X			X	X	HB-V0		X		X	X	XS	NP	75-95
Styrene acrylonitrile copolymers ##			X	X			X	X			X	X	HB-V0		X		X	X		NP	80-95
Vinyls	X		X	X	X	X	X	X			X	X	HB-V0	X	X	X		X	X	SL	65-95
Polysulfones			X			X	X				X	X	V1-V0		X			X	X		150-175
Thermosetting Plastics																					
Expoxies	X					X			X	X	X	X	HB-V0		X	X		X		SL	120-290
Melamines		X							X	X	X	X	V0		X	X		X	X	SL	100
Phenolics	X	X				X			X	X	X		HB-V0		X			X	X	D	120
Polyesters (other than moulding compounds	X			X	X				X	X	X	X	HB-V0		X		X		X	SL	150-210
Polyesters		X							X	X			HB-V0		X	X				SL	150-275
Silicones	X	X				X			X	X			HB-V0		X	X				SL-N	315
Ureas		X									X	X	V1-V0							G	75

** For General guidance only – Evaluate suitability of specific compounds upon detailed data from manufacturer.

* Per UL 94. Because of the complexity of flammability ratings, exact information on specific compounds should be obtained from the supplier of the plastic resins.

NP–needs protection, C–chalks, N–none, SL–slight, NL–nil, CO–colours, D–darkens, G–grays.

Available in glass filled forms which, in general, yield parts with improved toughness, higher rigidity, significantly higher heat resistance and slower burning rates.

S Rubber modified form.

Table 5.6.2 Properties of Plastics Used in Lighting (published by courtesy of IESNA)

The following information is collected for each type of refractor or lense:

a. installation year;
b. make and type;
c. material, treatment and transmittance;
d. type of mounting;
e. level of maintenance;
f. visible deterioration (bending, bulging, yellowing).

This data is compared with original specifications and renovation technical information to verify that:

- the installation conforms to engineering specifications;
- renovations used materials conforming to the technical performance intent of the design and use of space;
- the reflectance degradation does not exceed 10% and the yellowing factor, due to ultra-violet degradation does not exceed 3 in the Fad-O-Meter, type FDA-R. For flat glazing lenses the transmittance is checked by measuring the on-axis luminance of the luminaire with the lense on dividing it by the on-axis luminance of the luminaire with the lense removed, and multiplying the result by 100. Complex lenses such as fresnel, and prismatic lenses, and the yellowness factor should be checked by an independent lighting laboratory (see Appendices 5.15).

Corrective recommendations are given after evaluation of the data.

Luminaire Installation/Aiming

The installation and aiming of luminaires, where required, such as with floodlighting, and street lighting, is often critical to its proper luminous distribution.

Check the following points:

a. luminaire mounting assembly to be as per specification (check if it is properly suspended, mounted and leveled);
b. luminaire aiming for flood or road lighting is maintaining design requirements (check that mounting hardware, pole mounting stability, bracket tilt, luminaire tilt, and lamp socket position are as per design requirements).

Adjustments can often be done on site. However where they are difficulties, engage manufacturer's help, which usually consists of a trained individual with access to a laser aiming device and other needed equipment.

5.7 VDT ENVIRONMENTAL SURVEY

INTRODUCTION

The VDT environmental survey includes measurements of illuminance, luminance, contrast and transmittance/reflectance. It also requires a knowledge of the makeup of the visual display (i.e., use of line matrix or pixel matrix).

Refer to Appendices 5.4 and 5.5 for the general requirements of illuminance, luminance and transmittance/reflectance measurements.

STAGE I, VISUAL EVALUATION OF SPACE

Equipment required: polaroid camera, reduced floor plans, illuminance meter.

This consists of a careful walkthrough examination and annotation on a reduced set of plans of the following major characteristics, which impact on the quality of VDT space:

a. **VDT use:** data entry or conversational;
b. **Average task illumination:** data entry to have 500–700 lux; conversational to have 300–500 lux;
c. **Glare sources:** check from operator's normal working position for any glare sources in the field of view (i.e., windows, luminaires, screen reflections and other objectionable reflections); (see Lighting Survey Form, Appendix 5.4);
d. **Luminances:** check for perceived very light or very dark surfaces located in the field of view from the operator's normal working position; (see Lighting Survey Form, Appendix 5.4);
e. **Screen contrast:** check for excessive screen phosphor deterioration (i.e., faint display), and for presence of contrast adjustment controls.

STAGE II, FIELD MEASUREMENTS

Equipment required: as in Stage I plus a luminance meter, calibrated reflectance chart, photographic tripod with graduated angular adjustments, inclinometer, PWC visual evaluator.

Utilizing data collected in Stage I, undertake the following surveys and compare collected data with reference values listed in brackets "[ ]".

a. character height in mm: [3 mm]
b. screen glare: mount the luminance meter on the tripod at the observer's usual viewing angle, with its lens placed at the usual visual distance of the operator (eye–to–screen) and measure brightest visible spot and darkest visible spot. Calculate ratio of these two values: [3 : 1]
c. window glare: measure brightest area of luminance visible from operator's normal working position; [1200 cd/m²]
d. luminaire glare: measure brightest area of luminaire visible from operator's normal working position; [1200 cd/m²]

e. reflectances: measure average reflectances of ambient surfaces which are visible from operator's normal working position;

Ceiling	0.7 – 0.8
Walls	0.4 – 0.5
Screens	0.4 – 0.5
Floors	0.2 – 0.3
VDT	0.3 – 0.4
Drapes	0.3 – 0.4
Furniture	0.3 – 0.4

f. screen display contrast: display a text on the centre of the screen then using the same setting as in b, measure the luminance at the centre of the screen with text displayed and with text removed. Ratio the two values to calculate the approximate screen display contrast; [3:1 – 15:1]

g. light control: check light control's coverage and access to control station(s); check level of control; [Individual, handy, and variable control as much as possible]

A visual evaluator to test the visual acuity on site and lighting glare is available from PWC/Headquarters in Ottawa.

STAGE III, DETAILED FIELD MEASUREMENTS

Equipment required: as in Stages I and II plus a lens adapter for luminance meter to obtain a 20 degree field (approximately), light occlusion cup, magnifying lens (to examine pixel matrix details if unknown).

This type of survey should include interacting ergonomic issues, and analysis of actual visual display(s) contrast characteristics. Visual acuity tests, where possible, are desirable, to identify possible eye sight problems. A visual performance evaluator kit, available from PWC/Headquarters has visual performance analysis capabilities.

5.8 DAYLIGHTING SURVEY

INTRODUCTION

The examination of the impact that daylighting has on an interior environment is not an easy task. The multi–disciplinary nature of daylighting and its dynamic characteristics make this a complex task. This analysis of daylighting is limited to the following aspects:

a. determination of daylighting availability (approximate);
b. determination of beam daylighting penetration and daylighting zones;
c. daylight factor survey;
d. luminance and glare issues survey;
e. control issues survey;
f. maintenance issues;
g. daylighting quality field notes.

STAGE I: DAYLIGHT AVAILABILITY

Equipment and Materials required: Set of reduced architectural as–built drawings; Architectural Material list and glazing technical data; fit–up specifications and drawings; illuminance meters (2); luminance meter, walkie–talkie.

Daylighting availability is assessed by checking the following:

a. window glazings represent at least 20% of the interior window wall surfaces;
b. actual glazing transmittance for a 20% glazing is at least 70%. Examples of other glazings are found in Table 5.8.1;
c. drapes and blinds are easily adjusted to maintain the parameters in b. above;
d. average of all interior surfaces reflectances are at least 40% (see Appendix 5.5 for measurements of reflectance);
e. the "no sky line" falls at least on the first row of working surfaces, see Figure 5.8.1a.

If any of the above points are not met, daylighting does not make a significant contribution to task ambient illuminance levels and its presence is considered an amenity.

Average Room reflectances	0.30 (dark)			0.60 (light)		
Vertical Angle of Exterior Obstruction	85°	60°	30°	85°	60°	30°
Numbers of floors below a facing parapet on a 30 m wide street	0	3	7	0	3	7
Visible Transmittance of Glazing	(%)	(%)	(%)	(%)	(%)	(%)
0.10	160.1	226.8	453.6	91.5	129.6	259.2
0.20	80.1	113.4	226.0	45.7*	64.8	129.6
0.40	40.0*	56.7	113.4	22.8*	32.4*	64.8
0.70	22.9*	32.4*	64.8	13.0*	18.5*	37.1*

Notes:

1. The room is assumed to be 36 m^2, 6 m wide, 4 m floor to floor, 2.5 m floor to ceiling.
2. Percentages greater than 60% are not physically possible since the glazing percentage is the net area of glass compared to the total exterior wall area for the room.

* Indicate maximum acceptable glazing for typical energy conservation practices.

Table 5.8.1 Glazing Percentages Required for a 2% Average Daylight Factor

(solar time) Location	Lat.	January		March		June	
		10 a.m.	12 p.m.	10 a.m.	12 p.m.	10 a.m.	12 p.m.
Vancouver	49.2°	6 700	11 300	17 000	21 400	25 000	28 350
Edmonton	53.2°	7 300	13 000	18 900	24 000	23 400	26 700
Winnipeg	49.5°	9 440	15 200	20 470	26 000	23 800	27 300
Toronto	43.5°	12 000	18 700	19 600	26 240	27 770	32 500
Ottawa	45.2°	12 900	20 000	21 750	27 500	24 900	28 800
Montreal	45.5°	9 700	15 400	19 000	25 200	26 100	30 000
Halifax	44.4°	10 900	16 620	19 700	24 780	26 100	30 000

Table 5.8.2 Availability of Exterior Horizontal Illuminance (lux) for Selected Cities in Canada*

* Derived from data in May 1977.

STAGE II AND III: DAYLIGHT AVAILABILITY

The following publications on climatological data offer basic information from which it is possible to extract approximate daylighting data.

McKay, D.C., Morris, R.J., Solar radiation data analyses for Canada 1967-76 in six volumes, Canadian Government Publishing Centre, Supply and Services Canada, Ottawa, Canada, K1A 0S9; Cat. No.: EN56-64/(vol. #) 1985

volume 1 - The Atlantic Provinces	$30
volume 2 - Québec	$24
volume 3 - Ontario	$30
volume 4 - The Prairie Provinces	$36
volume 5 - British Columbia	$30
volume 6 - The Yukon and Northwest Territories	$18

Summaries for regional climates showing mean and number of sunshine hours for average days in each month are found in "Canadian Climate Normals 1951-1980", Vol. 9 - Sunshine 1982, Supply Services Cat. No. En56-60/7-1982.

Using the reference materials indicated above proceed as follows: Daylighting availability is found by selecting the proper value of Global Radiation (RFI) from above data base for the area under investigation and multiplying it by the average luminous efficiency of the sun (115 lumens/ watt).

The result is in lux and if percentage of clear and overcast skies are considered, it is possible to have an approximate average profile of local daylighting availability.

This information is used as an input into software packages designed to produce an array of data, ranging from illuminance and luminance mapping of any major surface within the room, to contrast and glare indices, to strategies integrating daylighting to electric lighting, to energy issues. (Refer to Appendix 5.16 for software listing.)

STAGE I AND II: BEAM DAYLIGHT PENETRATION AND DAYLIGHT ZONES

Equipment and Materials required: Site plan, building cross sections, protractor and sunpath diagrams.

1. Beam Daylighting Penetration

Beam daylighting penetration is done for worst-case conditions. It uses a protractor and sunpath diagrams, included in this appendix. Worst-case conditions are those work areas in close proximity to windows which receive direct beam daylighting sometime during the year. Follow these instructions:

a. select a reference target workstation;
b. prepare an elevation of the area showing external obstructions affecting daylighting penetration;
c. draw a line from the top of the workstation reference point through the window, to the top of the external obstructions and, using the

protractor, measure the angle that the line makes with the horizontal workplane; this angle is known as the obstruction angle;

d. take the sunpath diagram* for the latitude of the area and enter on it the obstruction angle on the ordinate (y) axis;

e. observe the area above the obstruction angle value: this indicates those times of the year when beam daylighting is visible on the work surface. Ideally this area should be zero. However if is is not, it can be reduced to zero by using window treatment techniques including blinds and screens;

f. Figure 5.8.1 offers an example. Here the obstruction angle is 45° for the lower floor shown. The sunpath diagram shows direct beam daylighting penetration to be worst on 21 June, when it lasts from 9 a.m. to 3 p.m. A short blind capable of blocking or controlling the upper portion of the window (20° approximately of obstruction), will solve the problem.

2. Daylight Zones

Daylighting penetration, which always excludes beam daylighting, is controlled by window sizes, their net transmittance and external obstructions. Generally it is possible to approximately describe three daylighting zones as follows:

- Zone 1, Primary Daylight Zone: This zone extends perpendicular from the window surface to a distance of twice the window height above 750 mm. Floor areas adjacent to large window areas are included to a distance of 3 m beyond the window edge (see Figure 5.8.2).
- Zone 2, Supplementary Daylight Zone: This zone extends from the boundary of Zone 1 to a distance of three times the window height above 750 mm. Floor areas adjacent to large window areas are also included to a distance of 3 m beyond the window edge (see Figure 5.8.2).
- Zone 3, Visual Access Zone: This zone includes all remaining floor areas from which a significant window area may be seen.

Note: The "no-sky point" is a physical limitation drastically reducing daylight penetration in a space and must be considered in the determination of the above daylight zones.

* Interpolation between two sunpath diagrams may be necessary to get correct local latitude values.

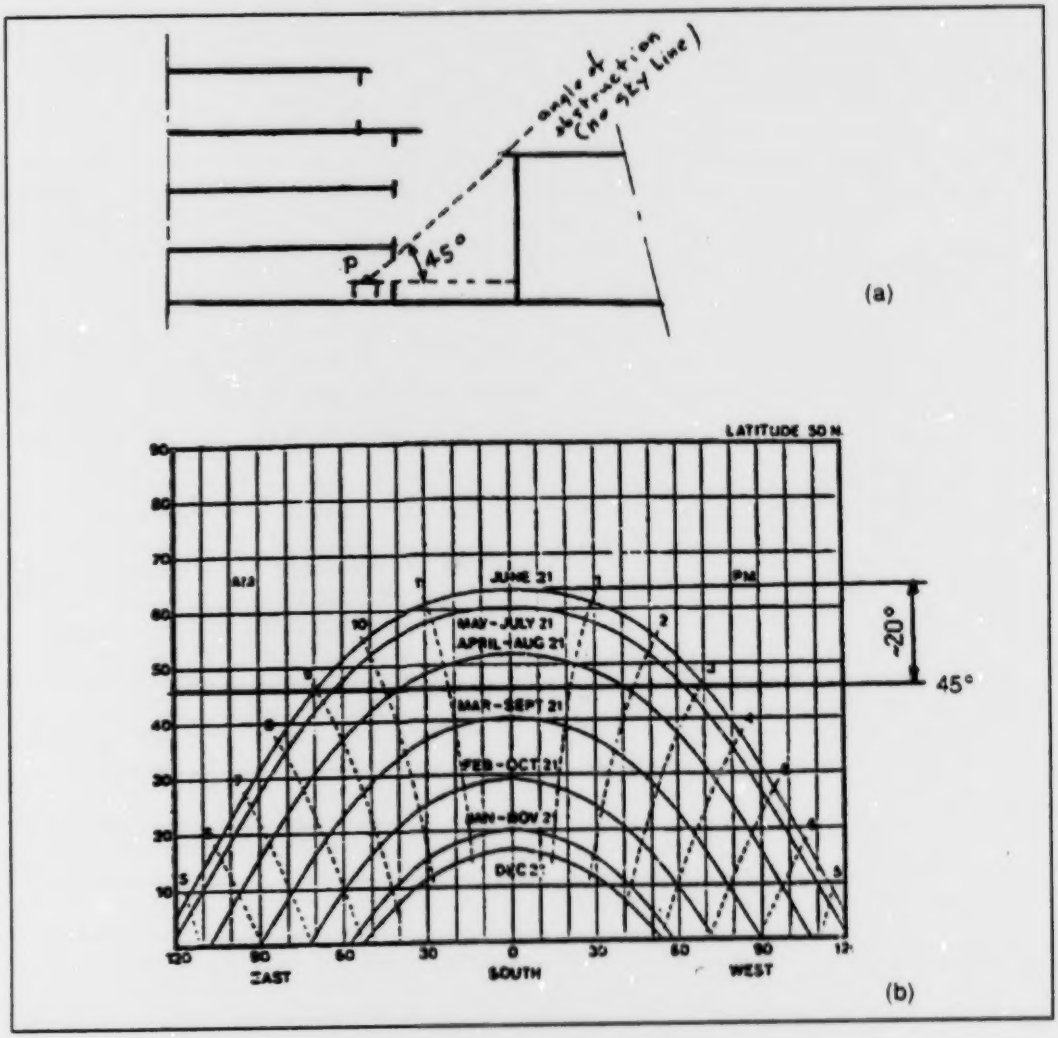


Figure 5.8.1 Determining direct beam daylighting penetration using sunpath diagrams for a location of 50°N latitude for STAGE I and II

Stage I: Select a reference point P and from it find the average angle of obstruction as shown in (a). Draw the line representing this angle, parallel to the "x" axis (i.e., 45°) as in (b). The area above the 45° line represents insolation times at the selected building interior point P, for various times during the year:

Stage II: Repeat but accurately represent all obstructions as they appear through the seasons, on acetate overlays. Evaluate insolation times by looking at areas under the curves in (b) as in Stage I.

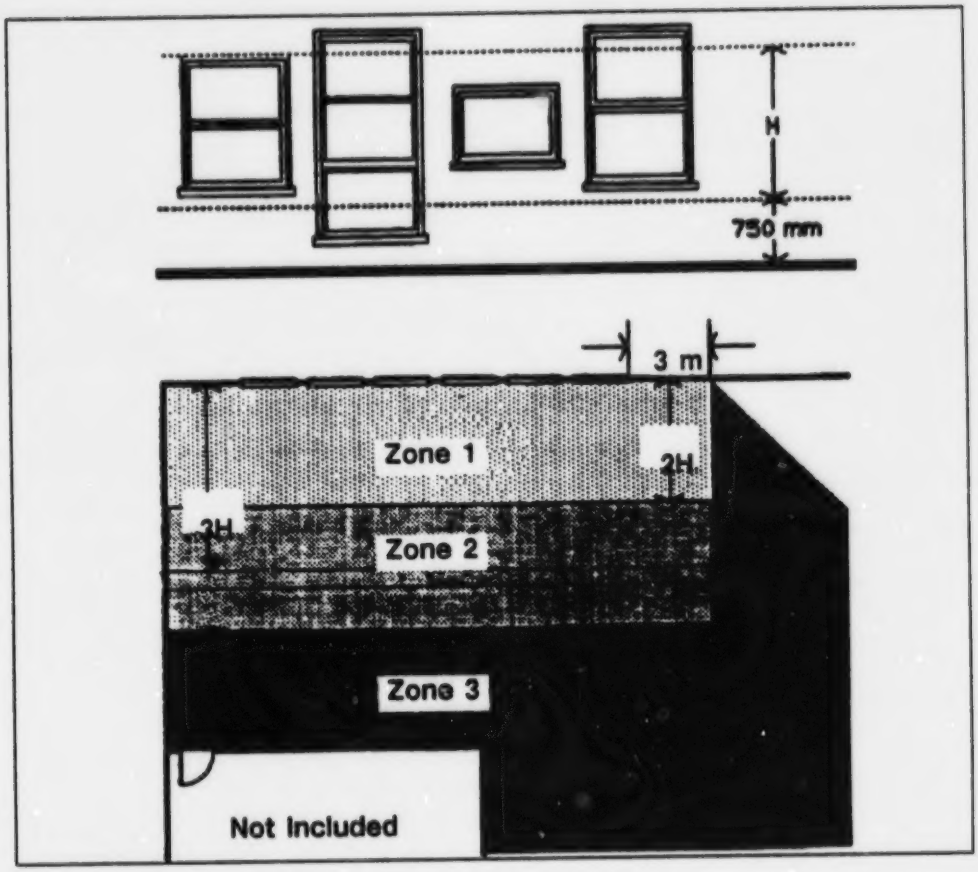


Figure 5.8.2 Determining Daylight Zones for STAGE I and II

Stage I: Daylight Zone 1 = 2 x Window height above 750 mm
Daylight Zone 2 = 3 x Window height above 750 mm
Daylight Zone 3 = any depth from which windows are visible

Stage II: Daylight Zone 1 = as above
Daylight Zone 2 = as above or where the minimum value is 2% DF* (inclusive of Zone 1)
Daylight Zone 3 = as above

* for definition of DF (Daylight Factor) see next paragraph

STAGE I: DAYLIGHT FACTOR SURVEYS

The daylight factor (DF) is simply the ratio of the horizontal illuminance, taken on a work surface, to the horizontal illuminance concurrently taken outside, under an unobstructed skyvault. The DF is a useful indicator of the percentage of exterior

daylight finding its way indoors. Average values of 2% to 5% in daylight Zones 1 and 2 confirm useful daylight contributions. Average DF exceeding 5% indicates possible glare and thermal problems.

An approximate method to calculate the Average Daylight Factor (ADF) for a space is to use the equation following:

$$ADF = \frac{WTc\theta}{A(1-R^2)}$$

Where: W = net area of glazing

Tc = transmission index of glazing

θ = vertical angle (degrees/ subtended by the sky visible from the centre of a window

A = total area of indoor surfaces (walls, ceilings, floors, windows)

R = area weighted average reflectance of all indoor surfaces part of A above

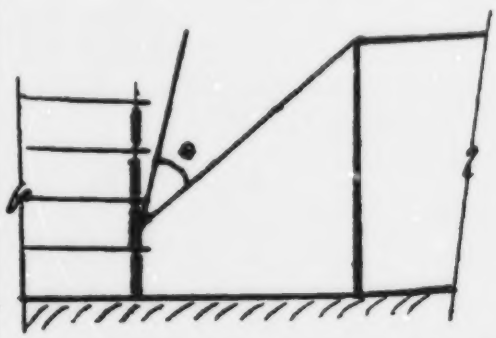


Figure 5.8.3 Vertical Angle θ

This equation is valid for shallow perimeter areas, limited by the following equation:

$$D = \frac{2wh}{(h+w)\ (1-Rb)}$$

Where: D = limiting depth

w = room width

h = height of window head above floor

Rb = area weighted average reflectances of surfaces in the half of the room remote from the window

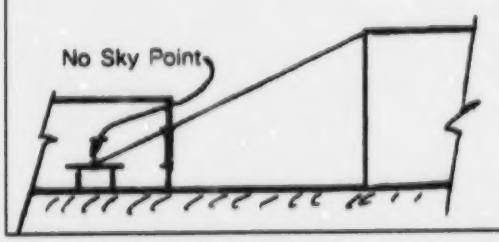


Figure 5.8.4 No Sky Point

When a room is lit from both sides the limiting depth can be doubled.

In addition to the limiting depth equation, the location of "no sky point" physically limits much of the daylighting contribution and is to be considered, along with D. In rooms satisfying the limiting factor D, the ADF is generally found at the mid-point of the room.

STAGE II AND III: DAYLIGHT FACTOR SURVEYS

The use of the average daylight factor equation is sufficiently accurate to satisfy Stage II requirements. Stage III requires the use of more sophisticated techniques. Two methods are described here, one using a suitable photometer and the other using a photographic technique.

Stage II: Luminance Meter Method

This is an approximate method to calculate the DF. Take a luminance measurement through the window at 42° above the horizon under CIE overcast sky conditions*. This measurement, multiplied by pi (3.14) and by the glass transmittance, represents the exterior horizontal illuminance.

Following this, measure horizontal illuminance at the workstation. The ratio of the second to the first value represents the DF.

For DF surveys proceed as follows:

a. select daylight zones according to similar orientation, elevation, external obstructions, similar architectural features, organization and use of interior spaces; ensure that the "no sky" line is not included;
b. wait for a CIE overcast sky condition*;
c. follow the attached standard field survey method.

Average Daylight Factor Measurement for Overcast Sky Conditions Only

For each floor or area selected, a 1,500 mm x 1,500 mm grid is located within the boundaries of daylighting Zones 1 (Primary Daylight Zone) and 2 (Supplementary Daylight Zone). Grid stations begin at a distance of 750 mm from the window walls and at least 750 mm from all other nearby walls.

Measurements

Outdoor horizontal illumination measurements must be taken under unobstructed CIE overcast sky* either simultaneous to grid-station measurements or immediately before and after. Use two meters and a walkie-talkie.

Before: _____ lux After: _____ lux

Grid-station measurements are taken with the room lights off at the 750 mm reference plane height for each grid point, following a path of consecutive loops (see diagram). Any blinds or draperies should be fully opened.

* CIE Overcast Sky is a uniformly cloudy sky where the luminance of the horizon is 1/3 of that of the zenith (overhead), for normal ground conditions, and goes to 1/2 for snow-covered ground conditions.

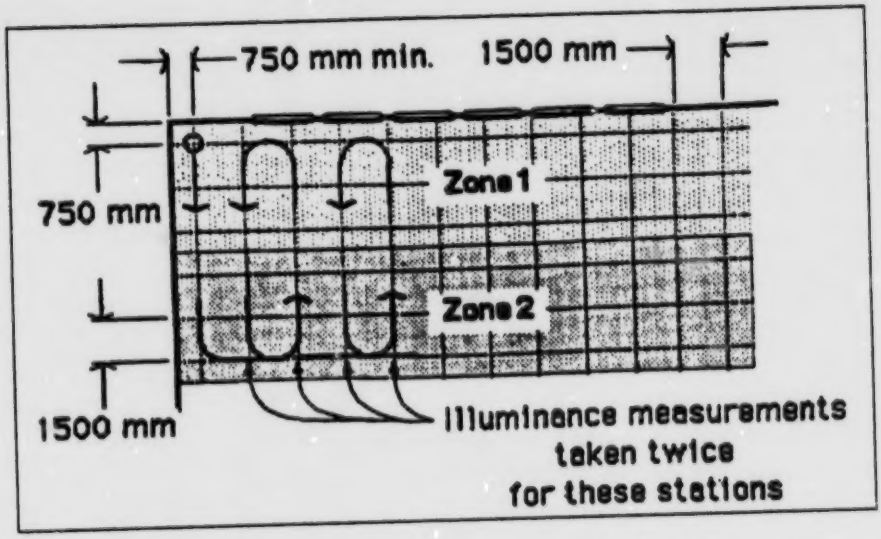


Figure 5.8.5 Daylight Factor Survey Grid

Calculations

Average Exterior Illumination = luminance at 42° x Glass Transmittance x 3.14

The average daylight factor for the area surveyed may be calculated as follows:

$$\text{Average Daylight Factor}(\%) = \frac{\text{Average Interior Illumination}}{\text{Average Exterior Illumination}} \times 100$$

Stage III: Photometer Method

This requires the use of a daylight factor meter (usually available from instrument rental companies or universities). If this meter is unavailable, use a luminance meter with multiple cell inputs.

Field surveys are done following the same steps previously identified for Stage II except the actual placement of the exterior reference luminance cell. This cell must be placed to "see" only an unobstructed sky vault.

Errors will be introduced in proportion to deviations from this reference condition.

It is suggested that a graphic recorder be used to continuously confirm and monitor the exterior reference luminance cell. This will provide the means to apply proper correction factors to the calculated DF to account for sky variability.

An easy and accurate evaluation of the Sky Component (SC) using the photographic method for determining daylighting potential can be found in Appendix 5.2 (6). This value, used in conjunction with the Externally Reflected Component (ERC) as shown in the equation below, gives the value of DF at a point.

$DF = a(SC + ERC) + (v \bullet e \bullet g/f)$;

Where: a, v, e = constants (see Tables 5.8.3, 5.8.4 and 5.8.5)
g/f = ratio of glazing to floor area
SC = sky component
ERC = externally reflected component (use an approximation of 1% of SG or extract from Table A9.1 of CIBS Code for Interior Lighting, 1984 also available from PWC/HQ - A&ES - Buildings)
Ignore if ERC angle is less than SC angle

Floor reflection factor	0.3			0.1							
Ceiling reflection factor	0.7			0.7			0.5			0.3	
Wall reflection factor	0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1	0.3	0.1
Room index	Values of a										
1.0	1.1	1.1	1.0	1.0	1.0	1.0	0.9	0.9	0.9	0.9	0.9
1.25	1.1	1.1	1.1	1.1	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1.5	1.2	1.1	1.1	1.2	1.1	1.1	1.1	1.1	1.0	1.0	1.0
2.0	1.2	1.2	1.1	1.2	1.1	1.1	1.1	1.1	1.0	1.0	1.0
2.5	1.3	1.2	1.2	1.3	1.1	1.1	1.2	1.1	1.0	1.0	1.0
3.0	1.5	1.4	1.3	1.4	1.2	1.1	1.3	1.2	1.1	1.1	1.0
4.0	1.7	1.6	1.4	1.5	1.3	1.2	1.4	1.3	1.2	1.1	1.0
5.0	2.0	1.8	1.6	1.7	1.4	1.3	1.5	1.4	1.3	1.1	1.0

Table 5.8.3 Constant "a" for the internally reflected component

Floor reflection factor	0.3			0.1							
Ceiling reflection factor	0.7			0.7			0.5			0.3	
Wall reflection factor	0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1	0.3	0.1
Room index	Values of v										
1.0	4.0	2.9	2.1	3.5	2.2	1.6	3.1	2.0	1.3	1.7	1.0
1.25	3.9	2.6	2.0	3.1	2.0	1.6	2.7	1.8	1.3	1.6	0.9
1.5	3.8	2.3	1.8	2.7	1.8	1.4	2.5	1.6	1.1	1.3	0.8
2.0	3.5	2.2	1.7	2.5	1.7	1.4	2.1	1.4	1.0	1.1	0.8
2.5	3.2	2.0	1.6	2.3	1.6	1.3	1.8	1.3	0.9	1.0	0.6
3.0	2.7	1.7	1.3	2.1	1.4	1.1	1.6	1.1	0.9	1.0	0.6
4.0	2.5	1.6	1.1	1.8	1.3	1.0	1.3	1.0	0.8	0.9	0.5
5.0	2.1	1.3	1.0	1.6	1.1	0.9	1.0	0.9	0.6	0.8	0.4

Table 5.8.4 Constant "v" for the internally reflected component

Angle of obstruction from centre of window (degrees above horizontal)	e
0° (i.e., unobstructed)	1.0
10°	0.9
20°	0.8
30°	0.65
40°	0.5
50°	0.35
60°	0.25
70°	0.18
80°	0.13

Table 5.8.5 Constant "e" for the Internally Reflected Component

STAGE I: LUMINANCE AND GLARE SURVEYS

These issues are best addressed by taking several luminance measurements from typical working positions and for typical fields of view. Tables 5.8.6 and 5.8.7 show typical target values for optimum ranges of luminances, as well as maximum values to limit possible glare conditions. Glare control can be exercised if the following points are considered:

1. Provide a window shade or blind device with a manual control that can block the view of the sky from 10 degrees above the horizon to the window head or the bottom of an external horizontal fixed shade.

   While in principle all shades go to the sill level, there are usually obstructions of some kind – trees, other buildings – to about the 10 degree elevation.

2. There should be a provision to reduce window luminance below 1200 cd/m² or to a 20:1 ratio with an adjacent light side wall or ceiling for VDT applications and 2000 cd/m² for other common office tasks. Maximum ratios anywhere in the field of view should not exceed 40:1.

   Sky luminances can reach 9,900 cd/m² in Canada (Kaufman 1981) while interior luminances due to task lights at 600 lux can be 150 cd/m². This produces a ratio of 66:1. Therefore unprotected windows far exceed the 40:1 limit and are considered glare sources.

Description	Range (cd/m²)
Walls, partitions	50–150
Ceilings	100–300
Task Area	100–400
Human features	250 approx.
Anywhere in the visual field	40:1 Maximum ratio of average to minimum values

Table 5.8.6 Operating Ranges for Ambient Luminances

Description	Luminance (cd/m²)
Visible sky	2,000
Sunstruck drapes	6,000

Table 5.8.7 Maximum Luminance Values

STAGE II AND III: LUMINANCE AND GLARE SURVEYS

Refer to luminance surveys in Appendix 5.4 for luminance issues. (Also see computer and modeling techniques in Appendix 5.16.) Glare issues are sufficiently dealt with in Stage I of this appendix and their analysis is properly documented in the software tools listed in Appendix 5.16.

STAGE I: CONTROL ISSUES SURVEY

Control issues refer to daylighting control in the absence of electric lighting and daylighting control in the presence of electric lighting. Both cases share many common points and control is exercised through proper window management, proper use of interior reflectances, sensible office furniture layout, and finally, by integrating daylighting with electric lighting. The following points should be checked:

a. check that windows exceeding 2,000 cd/m², which are by far the majority, are provided with a blind, drape, or shade mechanism which is easy to operate, and effective in finely controlling daylighting access. Horizontal venetian blinds, solar drapes and drapes with an even transmittance are the best solutions;

b. measure or estimate the average reflectance of ceilings, walls and floors. They should be in the 70–80%, 40–60% and 10–30% ranges, respectively. Walls opposite windows should have as high a reflectance as manageable to improve daylighting distribution. Window walls have similar requirements but in this case to reduce the possibility of glare sensation;

c. ensure that office furniture is not placed to force occupants to face windows. Best worker orientation is with the line of sight parallel to the window; second best is facing away from the window, although this should be avoided because of possible annoying shadows. Office partition shelves and other tall obstructing elements should be placed perpendicular to window walls, with shorter elements closer to the windows and gradually increasing in size towards the back of the room;

d. in Daylight Zones 1 and 2 note if there is any control of the electric lighting as a function of daylighting. This is normally achieved through selection of perimeter zones, wired and controlled manually or automatically, to take advantage of ambient daylighting.

STAGE II AND III: CONTROL ISSUES SURVEY

Detailed observations are required to identify the level of integration of electric lighting, daylighting, and the HVAC system.

The survey includes the following steps:

a. analyze the fenestration type and the control system; assess its ability to deliver daylighting with efficiency while affording glare control;
b. investigate if the top portion of the glazing is properly utilized as it is responsible for the largest daylight contribution;
c. investigate use of window glare control mechanisms (structural, fixed drapes, dynamic drapes) and assess performance according to the degree of control and ease of operation and maintenance;
d. observe strategies used to control electric lighting as a function of available daylighting. Note degree of control and tracking abilities of light sensing devices under sunset, sunrise and midday conditions: excessive or non-uniform dimming patterns indicate poor calibration, poor tracking, or both;
e. check daylighting controlled zones to determine how well they match the work zone requirements, including illuminance levels and luminance ratios; determine if activities in the space are restricted by these factors;
f. investigate the level of integration of the mechanical HVAC system, day lighting and electric lighting;
g. use appropriate software tools, listed in Appendix 5.16, to analyze lighting control and energy issues.

STAGE I: MAINTENANCE ISSUES SURVEY

Daylighting maintenance issues refer to maintaining the glazing and its treatment in good working order to maximize daylighting penetration. It also involves maintaining high reflective surfaces and coordination of daylighting controls and electric lighting controls. For specific information see Appendix 5.13.

STAGE II AND III: MAINTENANCE ISSUES SURVEY

After completing a Stage I survey, take the following steps:

a. investigate the appropriateness of the light-sensing device location: also check its calibration (consult the manufacturer for an inspection);
b. check the calibration of all control elements and functions (again consult with manufacturer);
c. investigate if office refurbishing or renovations has maintained reflectances and obstructions within the original specification requirements of the control system;
d. check that light sources and other controlled components have been maintained or replaced according to the control system requirements;
e. check location and use of switches, overrides and other control elements to ensure they are easily operable and fit current needs;
f. use software tools, listed in Appendix 5.16, to optimize lighting maintenance program(s).

STAGE I: DAYLIGHTING QUALITY FIELD NOTES

These notes list all major characteristics of the space affecting the quantity and quality of daylighting. Refer to the forms and example which follow.

Daylight Quality Field Notes

Building Name: _____ **Date:** _____

Address: _____ **Time:** _____

_____

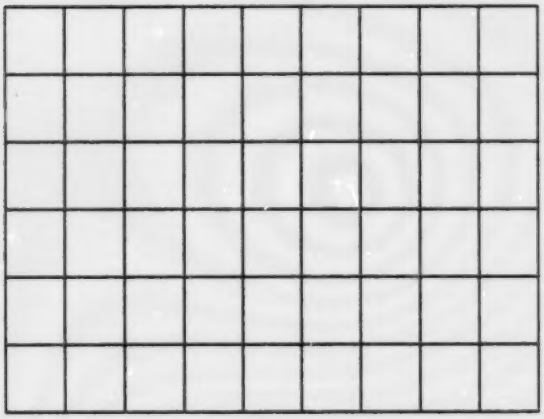
_____

_____

Observer: _____

Workspace: _____ **Floor:** _____

Sketch Plan



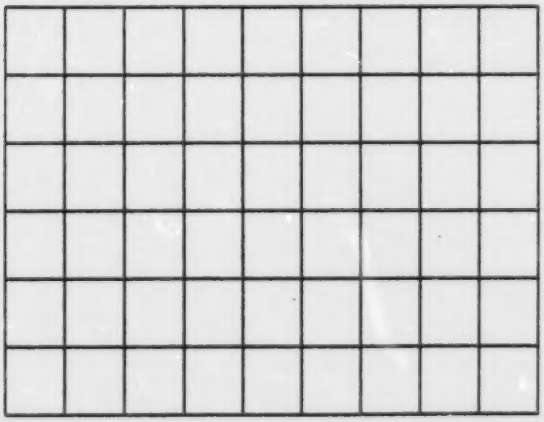
Major Orientation

N

W E

S

Sketch Section



Daylight Quality Field Notes

Artificial Lighting

Luminaires (Location and Type):

Controls:

Daylight Observations

Window Dimensions:

Type of Glazing:

Overhang:

Controls (Type of Blinds):

Controls (Type of Draperies):

Control Effectiveness (Adjustment Range):

Control Effectiveness (Redirection of Glare):

Personal Adaptations:

Daylight Quality Field Notes

General Notes

Daylight Quality Field Notes

Building Name: Administration Building **Date:** 19 June 1986

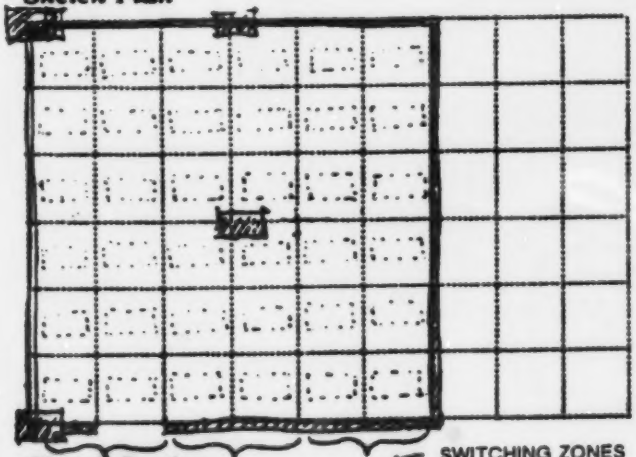
Address: Wesbrooke Mall **Time:** 2:00 p.m.

UBC

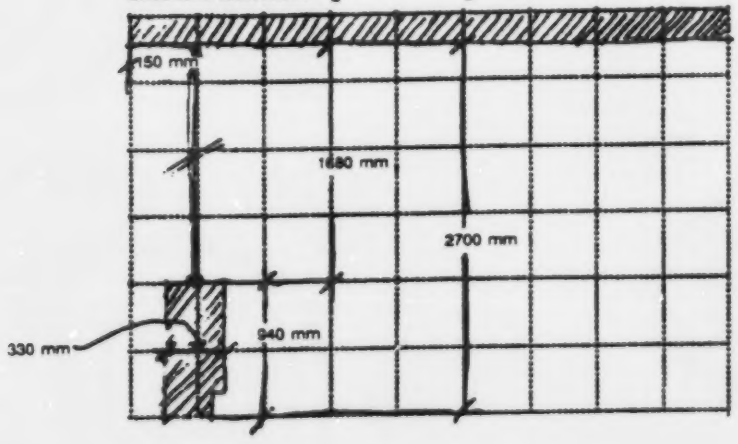
Observer: B. Clark

Workspace: Typical **Floor:** 2

Sketch Plan



Sketch Section



Major Orientation

N

W E

S

Daylight Quality Field Notes

Artificial Lighting

Luminaires (Location and Type):

- six rows perpendicular to window
- recessed fluorescents (incorporate air return)

Controls:

- three zones, parallel to window, two luminaires deep each

Daylight Observations

Daylight Aperture Dimensions: 1.680 mm in height, continuous strip (9 m)

Type of Glazing: single glazed, slightly tinted (66%)

Overhang: 150 mm

Controls (Type of Blinds): none

Controls (Type of Draperies): beige open-weave fabric

Control Effectiveness (Adjustment Range): draperies can completely obscure glazing, if desired

Control Effectiveness (Redirection of Glare): controls mask windows, do not redirect glare

Personal Adaptations:

Daylight Quality Field Notes

General Notes

*Finishes:

ceiling – white spraytex

window wall – brown enamelled mullions

side walls – pastel green

back wall, – pastel green, one shade darker than side walls

floor – medium olive asphalt tile, slightly reflective

*windows appear to be quite clean
*fluorescent fixtures are very dirty – part of air handling system

STAGE II AND III: DAYLIGHTING QUALITY FIELD NOTES

The evaluation of daylighting quality can be subjective, objective or both.

1. Subjective Evaluation

This draws from the evaluator's own knowledge and experience and is not quantifiable. Issues usually part of a subjective evaluation include:

a. sense of a well-balanced luminance environment, where architectural features are enhanced and modeling features of daylight evident and well utilized;
b. harmonious distribution and integration of daylighting with special features and operative requirements;
c. easy window access, offering psychological and visual relief;
d. variability of luminance intensities and patterns, offering a sense of dynamic contact with the outdoor environment.

2. Objective Evaluation

This evaluation is based on numeric empirical data, derived from expert consensus and limited scientific work. The principle elements to be investigated include:

a. luminance ratios and balances, achieved by limiting patterns of excessively low or high brightness and by limiting upper and lower values of acceptable ambient luminances. Appendix 5.3 offers an array of such luminance checks and balances;
b. glare control, achieved by reduction of high intensity luminance sources to within manageable values. Appendix 5.3 also offers glare limiting luminances;
c. daylight access and distribution control, achieved by suitable daylight penetration, treatment and control, as well as by furniture layout and observer's position;
d. integration with electric lighting and HVAC system, achieved using manual or automatic controls;
e. maintenance practices designed to maintain the operating characteristics of the daylighting system and designed to adapt it to the dynamic requirements of the space.

STAGE III: DAYLIGHTING POTENTIAL FIELD SURVEYS

There is sometimes a need to verify the potential for daylighting interior working spaces. The tools are often difficult to use or impractical.

PWC has developed a new photographic method which is fast, logical, accurate, versatile and economic to use. It leads to the determination of the Sky Component value for typical commercial glazings (6).

The Sky Component is the major element in the calculation of the DF and is sufficient to decide whether a detailed study is necessary.With 0.2% to 0.5% Sky Component,

there will be adequate background light provided, while with 0.5% to 1.5% there will be adequate lighting for common office tasks. Levels in excess of 5% suggest the possibility of glare situations.

The photographic method is available from PWC, A&ES/HQ, Ottawa.

This analytical tool is used in conjunction with the economic analysis, discussed next.

STAGE III: DAYLIGHTING POTENTIAL ENERGY SAVINGS FIELD SURVEYS

This is an approximate economic evaluation of savings due to the introduction of daylight into a space and is based on a number of assumptions. This economic evaluation is conducted in conjunction with the field survey on daylighting potential described in the previous section. The procedure for this economic analysis are available from PWC, A&ES/HQ, Ottawa.

Both methods quickly identify the important parameters of any daylighting design, utilizing a minimum of manpower and costs. If the results show positive values, then it is suggested that a full scale computer analysis be undertaken utilizing DOE2.1b or similar programs.

SUNPATH DIAGRAMS

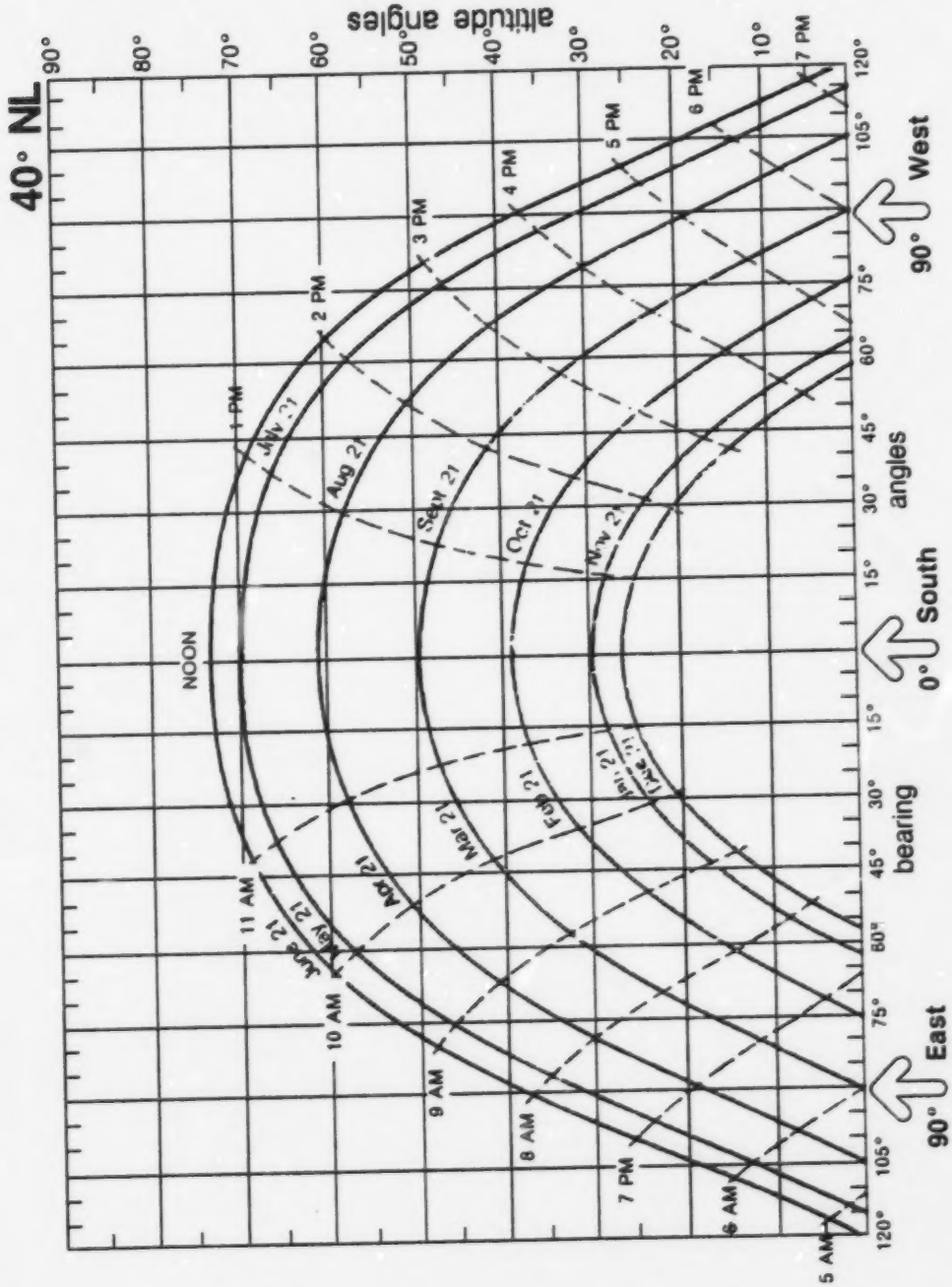


Figure 5.8.6 Sunpath Diagram: 40° North Latitude

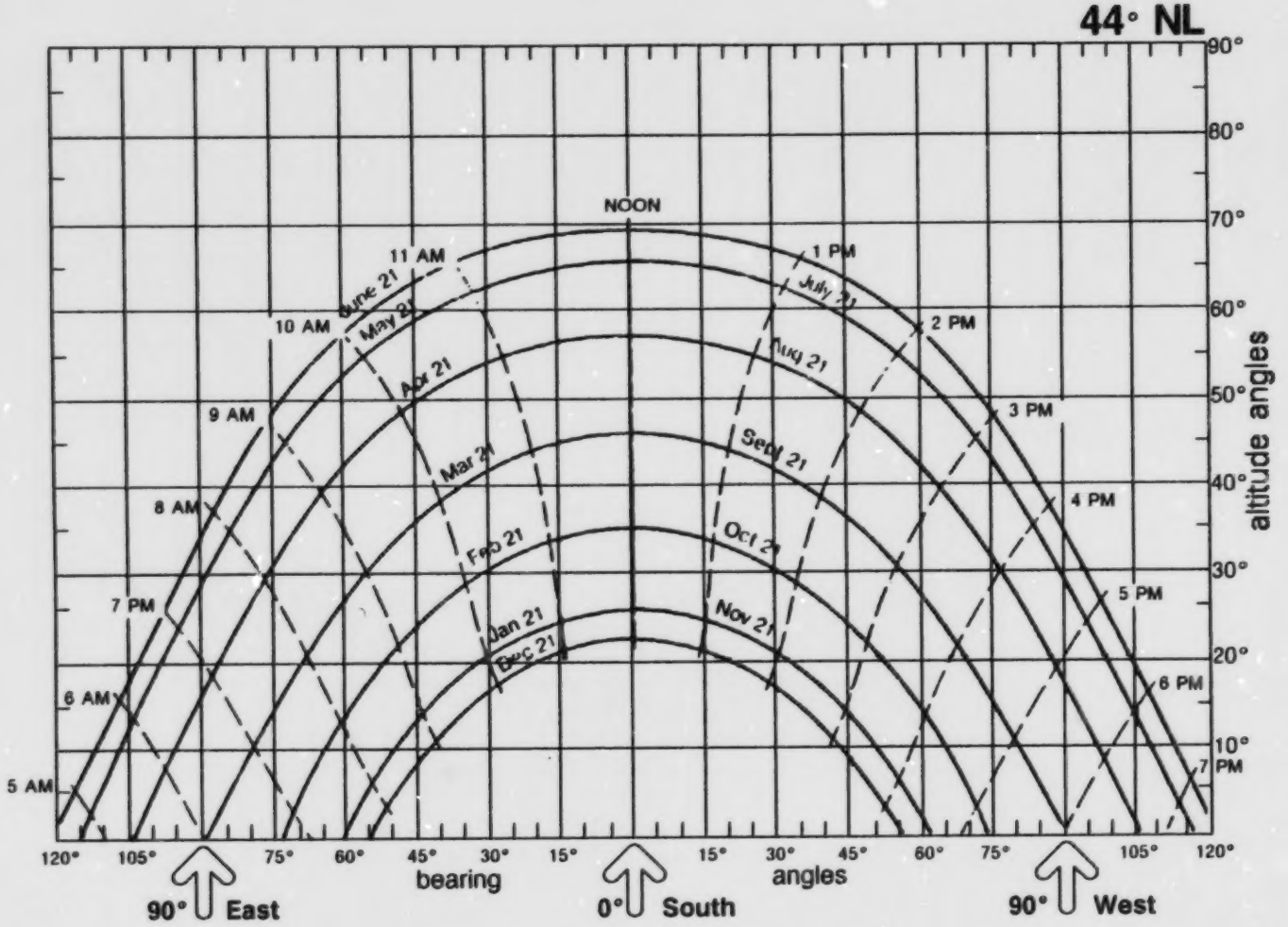


Figure 5.8.7 Sunpath Diagram: 44° North Latitude

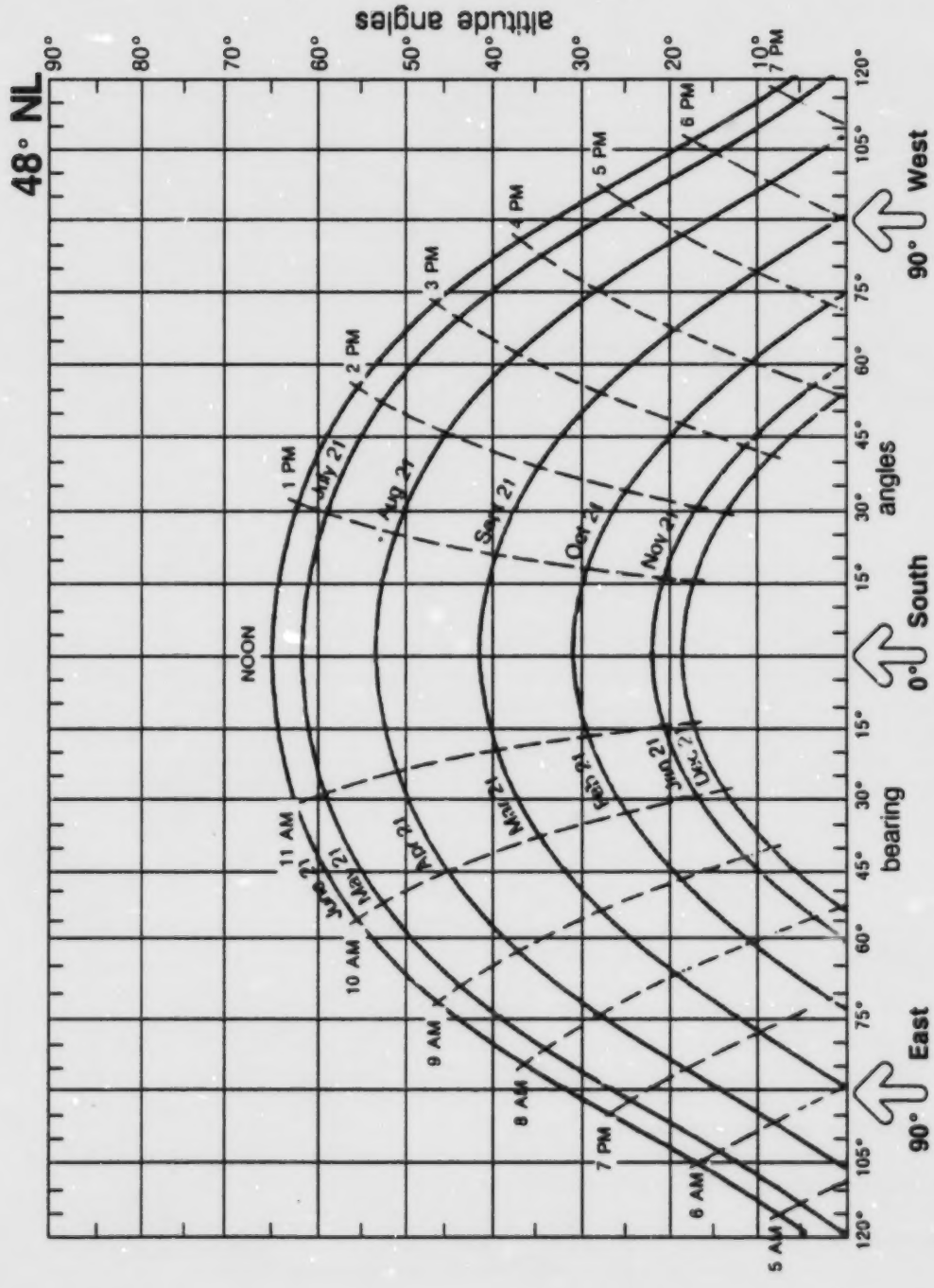


Figure 5.8.8 Sunpath Diagram: 48° North Latitude

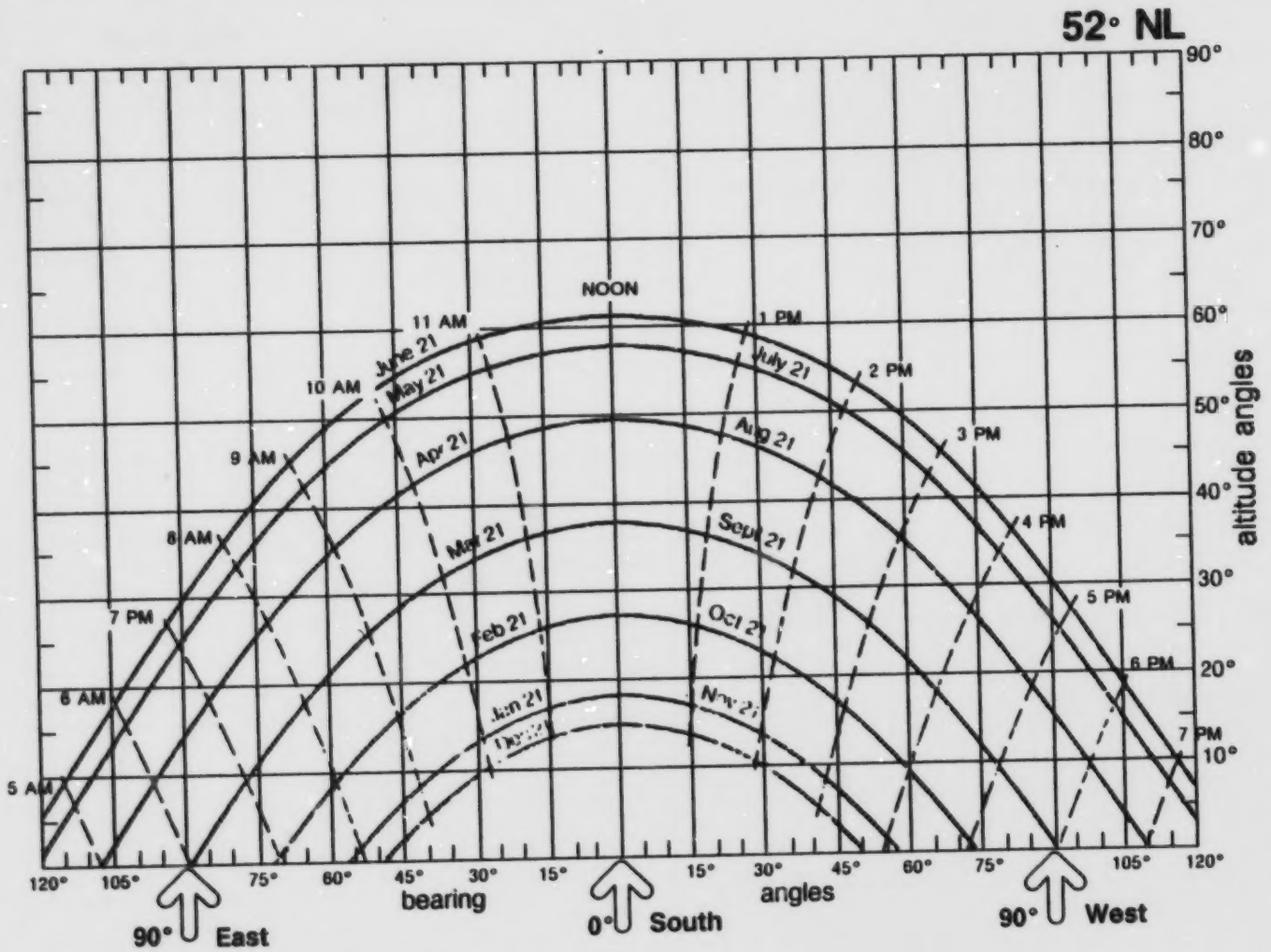


Figure 5.8.9 Sunpath Diagram: 52° North Latitude

5.9 VISUAL TASK SURVEY

INTRODUCTION

Visual task surveys identify the visual task and its lighting requirements. The visibility of typical office visual tasks is dependent on:

a. age of the observer and level of visual acuity;
b. size of the visual display (e.g.: written text);
c. reflectance of the visual display background;
d. importance of speed and accuracy;
e. contrast of visual display;
f. legibility of the visual display.

Most factors have been found to be easily measurable, except for the legibility of the visual display, which may be affected by smudges, unclear printing patterns, poor photocopy or carbon paper, poor handwriting and the like. However legibility problems can be solved by using proper judgment and are not discussed here. What is discussed instead is the determination of the difficulty of visual tasks.

STAGE I AND II, VISUAL TASK SURVEY

Instrumentation: illuminance meter

General Remarks

This is conducted using the IESNA Illuminance Selection Criteria Table as a guideline (see Appendix 5.2). The table explains, in detail, the type of tasks commonly found in offices and rates their difficulty using parameters a. through d., above. The selection procedure leading to a simple illumination value, is however, often based on subjective evaluation and personal experiences of the visual environment. To simplify this process, use the approach described below, based on work done at NRCC/IRC.

Rating the Visual Tasks

1. Prepare a table listing all types of visual tasks found in the office environment, using Tables 5.2.1 and 5.2.2; determine from managers the importance of speed and accuracy, whether critical or noncritical;
2. Group tasks according to common visual requirements;
3. Refer to Table 5.9.1 and enter each visual task in the appropriate illuminance category, in relation to difficulty of visual task and importance of speed and accuracy, determined above, to obtain a base illumination level;
4. Measure the task background reflectance (see Appendix 5.5) and determine the age of the worker;
5. Refer to Table 5.9.2 and enter the age and task background reflectance to determine the appropriate illuminance multiplier;
6. Multiply the base illumination level, found in 3 above, by the illuminance multiplier to obtain the required illuminance level.

Illuminance category	Difficulty of the visual task based on target contrast and size[2]	Importance of speed and accuracy	
		noncritical	critical
A	Movement through public spaces[3]	50	75
B	Infrequent reading or writing task; high contrast and large size (e.g., type written page)	100	150
C	Easy but frequent reading or writing task; high contrast and large size (e.g., type written page)	200	300
D	Moderately difficult reading or writing task; low contrast or small size (e.g., penciled or mechanical drawings)	300	450
E	Difficult reading or writing task; low contrast and small size (e.g., photocopy of a blueprint)	500	750

NOTES

1 The reference illuminance values given here assume high task background reflectance (<35). Increases to the recommended illuminance levels for lower task background reflectances and for older workers are obtained from Table 5.9.2.

2 Contrast is defined as $(L_b - L_t)/L_b$, where L_b is the luminance of the background and L_t is the luminance of the target. Based upon the visual performance model by Rea (1986), low contrast is defined as anything below 0.3. Size is determined in terms of minute of visual arc. Based upon the work of Legge, et al (1985), small size is defined as anything less than 20 minutes of arc (8 point type, which is about 2 mm high, is approximately equal to 20 minutes of arc at a "normal" viewing distance of 40 cm).

3 The floor is assumed task background.

Table 5.9.1 Task Categories and Reference Illumination Levels[1]

		Age (in years)				
		Under 30	30–40	40–50	50–60	over 60
Task	>0.8	1.00	1.18	1.43	1.82	2.50
Background	0.8 – 0.6	1.25	1.48	1.79	4.14	3.12
	0.6 – 0.4	1.67	1.97	2.39	3.04	4.18
Reflectance	0.4 – 0.2	2.50	2.95	3.58	4.55	6.24
	0.2 or less	5.00	5.90	7.15	9.10	12.50

Table 5.9.2 Adjustments to Reference Illuminances

The illumination levels so obtained are useful to compare with task illuminance survey results to verify compliance with PWC standards. However a separate check must be done to ensure compliance with Labour Canada COSH Regulations.

STAGE III, VISUAL TASKS SURVEY

Instrumentation: illuminance meter, luminance meter, inclinometer, visual performance evaluator kit

Visual tasks considered here are those of unusual nature and not found in any IESNA literature. This may include common tasks but viewed in non–standard visual environments (e.g., special mail processing plants, multi color forms, maps). Because of the very specialized nature of this stage, it is suggested that PWC HQ. be contacted for further information.

5.10 EMERGENCY LIGHTING SURVEY

INTRODUCTION

Emergency lighting is regulated by COSH Regulations administered by Labour Canada and by provincial and municipal by-laws.

Most buildings in Canada have emergency lighting systems installed according to NBC Sections 3.2.7.3, 3.3.3.3, 9.9.11, and 9.35.3.1, requirements.

However for all federally regulated enterprises the foremost regulations which presently apply are those established by Labour Canada (see Appendix 5.2) and emergency lighting must conform to these regulations.

STAGE I: ILLUMINATION LEVELS

Instrument: Illuminance meter

Average illumination levels should be a minimum maintained horizontal value of 10 lux along the entire escape route.

Illuminance is surveyed using grid 0.5 m square and placing the meter's photocell at the center of the square, on a leveled stand 1 m from the floor. The total width of the grid system should not exceed 2 m and it should be centered along the escape/egress route.

In addition to the above survey note the following:

- areas not served by emergency lighting should have at their egress door, a horizontal illumination level of at least 5 lux average at 1 m height;
- fire alarm call points and fire fighting equipment provided along escape routes should be illuminated at least by 10 lux average at 1 m height;
- handicapped people and special situations (e.g., special security areas, and dangerous materials) could require special consideration and should be resolved on a case-by-case basis;
- flood type luminaires should be aimed to follow the predicted flow direction of escape routes and aimed to prevent glare;
- exit doors should be provided with emergency lighting in the immediate vicinity.

NOTE: Emergency lighting which utilizes a percentage of ceiling mounted fluorescent night lights can be checked during the building silent hours.

Remote incandescent units, normally battery powered, can be checked by energizing their built-in check circuit and following the manufacturer's guidelines, at any time that is convenient.

STAGE II: EMERGENCY POWER SUPPLY

Instrument: Voltmeter, Ammeter, and shunts, kW meter

The type of emergency lighting system power supply (dedicated emergency AC voltage power supply, stand-by diesel power supply, central or local DC power supply) is

investigated. With the help of an electrical engineer, check that the power supply is in good working condition, properly sized for the load, with the required transfer switches and interlocks in good operating condition, and with the required maintenance schedule properly followed.

STAGE III: EMERGENCY LIGHTING SIMULATION

This is conducted during building silent hours or, preferably during non-working days.

Required personnel are: electrical engineer, building operator and fire commissioner.

A total building power failure is simulated. All emergency lighting systems are checked for compliance to applicable regulations.

Power supply loading capacities and battery loading tests are conducted to verify their ability to carry the load. Refer to the National Fire Code Parts 6 and 7.

EMERGENCY LIGHTING SYSTEMS MANDATORY REQUIREMENTS

These are based on NBC 1985, NMS 1984, National Fire Code, Parts 6 and 7, and Labour Canada COSHR 1984 and their most recent revisions.

Labour Canada is responsible for this section under "Levels of Lighting", PART VI of COSH Regulations.

5.11 EXIT LIGHTING SURVEY

INTRODUCTION

Exit lighting is considered part of the Emergency Lighting System because it serves to indicate pre-established egress/escape routes, and because it is fed from the same emergency power services. Refer to Appendix 5.10 for specific information on emergency lighting. There is no uniform approach to exit lighting in Canada. This results in a bewildering array of systems under federal, provincial or local jurisdiction.

The federal jurisdiction is now represented by Labour Canada. No specific illuminance or luminance requirements are identified by COSH Regulations and in this section, recommendations are based on current NBC requirements, National Master Specifications (NMS), the National Fire Code requirements and IESNA recommendations.

STAGE I AND II SURVEYS

Equipment: Polaroid camera, measuring tape

The following is recommended:

1. identify the building escape route;
2. ensure that this route is identified by NBC, FCC and NMS approved exit signs (Figures 5.11.1, 5.11.2 and 5.11.3) so that there is at least one exit sign visible from any point along the route;
3. in open areas, where several signs may be visible, check that they are spaced not more than 10 metres apart;
4. take pictures and record perceived visibility problems on them.

STAGE III SURVEYS

Equipment: In addition to Stage I, add a 1° luminance meter

The following is recommended:

1. measure exit sign luminance and ensure it is at least an average of 7 cd/m²;
2. check luminance uniformity of exit signs to comply with maximum variations, from the average level measured in 1 above, while ensuring uniformity does not exceed an average to minimum ratio of 2:1;
3. test visibility of exit signs under building emergency power conditions and note if ambient luminances reduce it to unacceptable levels. This means inability or difficulty in reading signs at 30 m distance.

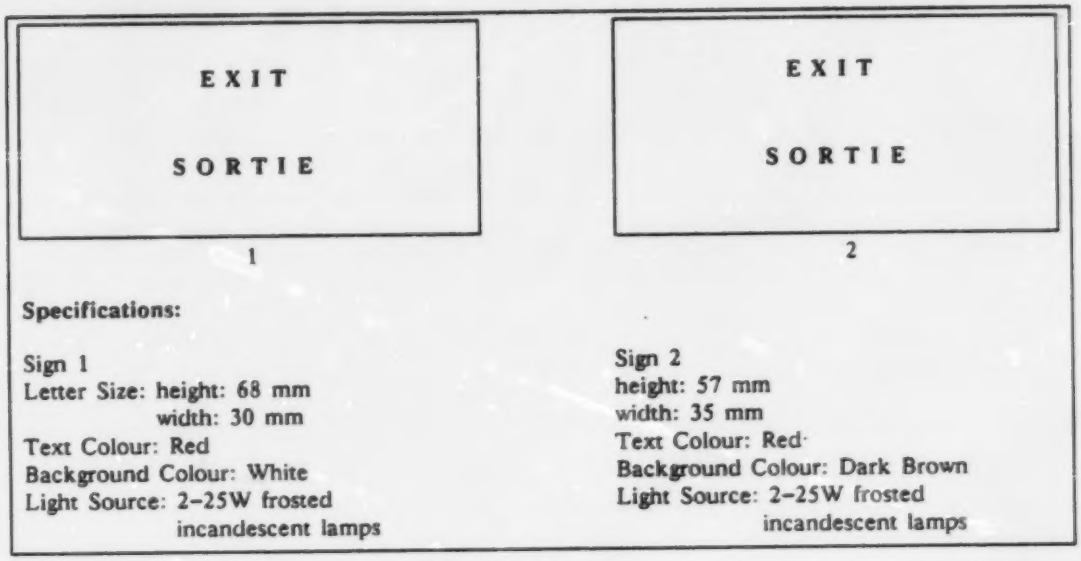


Figure 5.11.1 FCC Approved Exit Signs

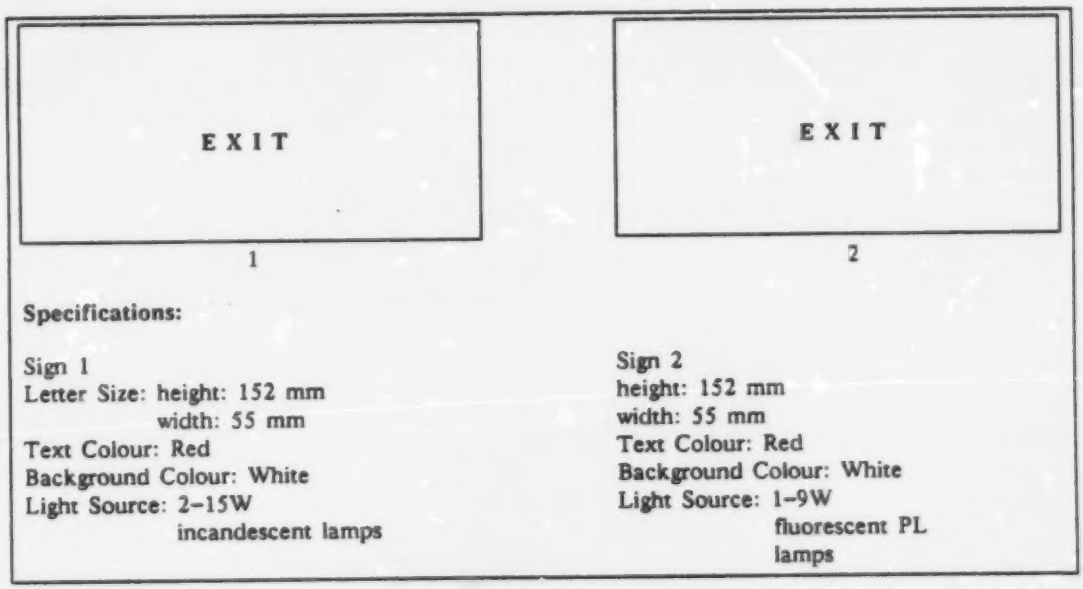


Figure 5.11.2 NBC Approved Exit Signs

1

2

Specifications:

Sign 1
Letter Size: 150 mm high
13 mm wide
Text Colour: White or Red
Background Colour: Red or White

OR

Text Colour: Red
Background Colour: Black

OR

Text Colour: Red
Background Colour: Die–cast aluminum

Light Source: 2–25W
incandescent lamps

Sign 2
Letter Size: 70 mm high
13 mm wide
Text Colour: White or Red
Background Colour: Red or White

Text Colour: Red
Background Colour: Black

Text Colour: Red
Background Colour: Die–cast
aluminum

Light Source: 2–25W
incandescent lamps

Figure 5.11.3 NMS Approved Exit Signs

5.12 LIGHTING ENERGY MANAGEMENT SURVEY

INTRODUCTION

The lighting energy management survey is used to determine the compliance of the building facility to power and energy upper limit values as set in the PWC "Office Lighting Standard" (see Appendix 5.2).

The methods indicated here are not substitutes for lighting design, but merely represent a quantitative evaluation of power and energy in a space.

STAGE I SURVEY

Equipment and material required: electric multi-meter, set of as-built plans, list of installed luminaires and their power ratings, inclusive of ballasts.

The building is surveyed in detail to determine the appropriateness of connected lighting power loads, schedules of operation, and control zones, keeping in mind the quantity and quality of lighting requirements. The interior and exterior spaces are checked and analysed separately. All spaces must be surveyed and all loads related to lighting and lighting controls must be included, such as ballasts, and controllers. The following process is suggested:

a. compile a list of all luminaires used, including task types, and ensure that their quantity, location, rated wattage and connected wattage including auxiliary devices, is identified;

b. compile schedules showing: (i) interior and exterior lighting zones and their operation profiles (e.g.: Zone A, luminaire 1c, 2b, 3e; 15 KW connected load for 8 hrs/day, 250 days/year (normal working hours); 10 KW connected load for 2 hrs/day, 250 days/year (cleaning hours); 2 KW connected load for 2 hrs/week, 20 weeks/year (overtime)); (ii) total connected power and yearly energy for both interior and exterior facilities;

c. determine for interior areas:

- total illuminated usable office area
- total illuminated service area;

d. referring to step b. and c., calculate the average connected power and yearly energy per unit area for gross office areas and for service areas;

e. check that values in d. do not exceed 22 W/m^2 and 250 $MJ/m^2/yr$ for gross office areas and 10 W/m^2 and 130 $MJ/m^2/yr$ for service areas;

f. determine the following for exterior areas:

- total illuminated driveways length
- total illuminated entrances length
- total illuminated parking areas length;

g. refer to step f. and calculate the average connected power and yearly energy per linear metre of all individual exterior zones previously identified and verify that the following limits are not exceeded:

- 9W/m and 150MJ/m/yr for driveways
- 40W/m and 700MJ/m/yr for entrances
- 20W/m and 350MJ/m/yr for parking;

h. check for adequacy of lighting zones size, location and operation in meeting the occupancy schedule;

i. check for use and integration of daylighting with other building systems;

j. check for opportunities of retrofitting energy saving devices.

What to Consider	What Can Be Done in New Construction	What Can Be Done in Existing Spaces	Resource and Comments
1. The lighting needs – for productivity, safety and esthetics. a. Seeing tasks b. Seeing task locations c. Purposes of nonseeing task areas d. Illumination recommendations e. Uniform lighting f. Nonuniform lighting	Seeing tasks and their locations should be identified so that recommended illuminances can be provided for those tasks with less in surrounding noncritical seeing areas. Where there are no tasks, there is no visual need for task levels. Then safety and esthetics are of prime consideration. When tasks and locations can be identified, it may be possible to use a nonuniform lighting system, such as a nonuniform pattern of luminaires arranged to light work stations or built–in or supplementary lighting at work stations, coordinated with a general lighting system. When tasks and their locations cannot be identified, an illuminance can be selected for the expected tasks and a uniform pattern of luminaires installed with controls for lowering the level at specific points when no tasks are present.	Seeing tasks and their locations should be identified so that recommended illuminances can be provided for those tasks with less in surrounding noncritical seeing areas. Where there are no tasks, there is no visual need for task levels. Then safety and esthetics are of prime considerations. Since tasks and their locations can be identified, a lighting survey would show where illuminances are in excess of recommended maintained values. Lighting then can be adjusted to meet the recommendations. Careful consideration should be given at task locations that any change in the lighting system will not produce veiling reflections in the tasks.	Other sections of the Handbook should be consulted for specific lighting needs.

Table 5.12.1 Lighting Considerations and Ideas for Energy Management (Table 5.12.1 extracted from IES Reference Handbook, 1987 provides some basic considerations and action plans.)

What to Consider	What Can Be Done in New Construction	What Can Be Done in Existing Spaces	Resource and Comments
2. Luminaires a. Effectiveness for task lighting b. Effectiveness for non-task lighting c. Efficiency d. Head transfer capability e. Cleaning capabilities	In selecting a luminaire for task lighting consideration should be given to its effectiveness in providing high task contrast (minimum veiling reflections) and sufficiently high visual comfort (VCP). Luminaire light distribution and appearance are also important, particularly for esthetics, but consideration also should be given to efficiency. Luminaires with heat transfer capabilities should be considered so that the lighting heat can be utilized or removed and coordinated with the building thermal design and total building energy use. See Section 2. Luminaires that can be cleaned easily and those with low dirt accumulation will reduce maintenance needs and costs.	Review luminaire effectiveness for task lighting and efficiency, and if ineffective or inefficient consider luminaire or component replacement. Check to see if all components are in good working condition. Transmitting or diffusing media should be examined and badly discoloured and depreciated media replaced to improve efficiency (without producing excessive brightness and unwanted visual discomfort).	Luminaire manufacturers' data are useful guides in determining luminaire effectiveness in terms of comfort (VCP), efficiency and ability to provide high contrast rendering. Energy use will be affected by luminaire light source and distribution characteristics as shown in one study. The study shows that for a medium size room, indirect, incandescent luminaires can consume over 5 1/2 times the energy compared with a direct, fluorescent system, for the same hours of use and average illuminance (but not the same light quality).

Table 5.12.1 Lighting Considerations and Ideas for Energy Management (Table 5.12.1 extracted from IES Reference Handbook, 1987 provides some basic considerations and action plans.) (cont'd)

What to Consider	What Can Be Done in New Construction	What Can Be Done in Existing Spaces	Resource and Comments
3. Light sources (lamps and ballasts) a. efficacy (lumens per watt) b. Colour (chromaticity) c. Colour rendering d. Lumen maintenance	Highest efficacy lamps and lamp ballast combinations should be used that are compatible with the desired light source colour, colour rendering capabilities, source size, life and light output depreciation. Compare sources being considered on basis of life cycle cost and energy use through life. Consider multi-level ballasts for flexibility in achieving nonuniform lighting as needed in hour-to-hour operations throughout each day or with changing work layouts over the years. Consider reduced current ballasts where module size and/or luminaire spacing permit needed illumination to be achieved.	Where inefficient sources are used, consider relighting with more efficient sources, compatible with desired light source colour and colour rendering capabilities, base on life cycle costing. Consider reduced wattage fluorescent lamps in existing luminaires where 10 to 20 percent reduction in illuminance can be tolerated. (With improved maintenance procedures – periodic cleanings, group relamping – as much light can be obtained as with standard lamps.) Consider multi-level ballasts for flexibility in varying light during occupied hours and cleaning periods, and reduced current ballasts where a reduction in illuminance can be tolerated.	Light source efficacy (lumens per watt) varies with lamp type and within types. Section 8 of the 1984 Reference Volume and lamp manufacturers' catalogues will provide lumen output, lumens per watt, life and lumen maintenance data as well as cost for comparison purposes.

Table 5.12.1 Lighting Considerations and Ideas for Energy Management (Table 5.12.1 extracted from IES Reference Handbook, 1987 provides some basic considerations and action plans.) (cont'd)

What to Consider	What Can Be Done in New Construction	What Can Be Done in Existing Spaces	Resource and Comments
4. Daylighting a. Availability of daylight b. Fenestration (windows, skylights) c. Controls	Evaluate the daylighting potential – the levels and hours of availability – keeping in mind that glare from fenestrations should be controlled to the same degree as from luminaires and that the heat gained or lost through fenestration needs to be coordinated with the building thermal system. Coordinate the electric light design with the daylighting so that glare, heat and illumination are controlled. Consider the use of "high performance" heat reflecting insulating glass in windows to minimize heat gain in summer and heat loss in winter, while permitting a view of the exterior.	If daylighting can be used to replace some of the electric lighting during the substantial periods of the day, lighting in those areas should be dimmed or switched off. If control is not provided, consider adding controls based on life–cycle–costing. Evaluate the effectiveness of the existing fenestration shading controls (interior and exterior) for possible replacements or additions.	Section 7 and 9 of the 1984 Reference Volume provide useful information on availability of daylight, daylight control systems, and design and evaluation methods. Recent data from manufacturers of fenestration materials and controls should be consulted.

Table 5.12.1 Lighting Considerations and Ideas for Energy Management (Table 5.12.1 extracted from IES Reference Handbook, 1987 provides some basic considerations and action plans.) (cont'd)

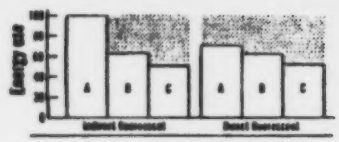
What to Consider	What Can Be Done in New Construction	What Can Be Done in Existing Spaces	Resource and Comments
5. Room surfaces	Work with the interior designer toward the specification of room surface and equipment reflectances at the higher end of recommended reflectances, not forgetting the importance of proper colour schemes for esthetics. (Reflectances higher than those recommended may produce excessive luminance ratios and glare.)	Where the reflectances of the room surfaces are lower than, or at the lower end of the recommended reflectance range, consider repainting using matte paints with reflectances toward the upper end of the range. When equipment is replaced, select light colour finishes. (Reflectances higher than those recommended may produce excessive luminance ratios and glare.)	The use of higher reflectance finishes saves energy. Below is a chart showing the decreased energy needs for equal general illlumination in a medium size room with improved reflectances. Reflectances are: Ceiling Walls Floor A 50 30 10–Not Recommended B 80 40 20 C 90 60 40 The grayed area shows percent energy savings 

Table 5.12.1 Lighting Considerations and Ideas for Energy Management (Table 5.12.1 extracted from IES Reference Handbook, 1987 provides some basic considerations and action plans.) (cont'd)

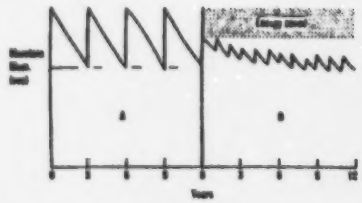
What to Consider	What Can Be Done in New Construction	What Can Be Done in Existing Spaces	Resource and Comments
6. Maintenance procedure	Carefully consider a planned lighting maintenance program early in the design stage to allow for desired maintained levels using less equipment and less installed lighting wattage. Also consider the daylighting (fenestration and controls) maintenance program when planning on the daylight contribution to the desired illuminance levels. The owner must be committed to the maintenance program used in the lighting system design. If not the lighting will be less than planned and will be an energy waster.	Reevaluate the present lighting maintenance program and revise it as necessary to provide desired maintained illuminances. This may allow some reductions in lighting energy.	The diagram below shows the effect of maintenance procedures on energy use. In system A, luminaires are cleaned and relamped every three years. In system B, luminaires are cleaned every year and one-third of the lamps are replaced every year. For equal maintained illuminance over a 12-year period, the more frequent cleanings and relampings in System B saves about 15 percent energy use due to the need for less equipment initially. 

Table 5.12.1 Lighting Considerations and Ideas for Energy Management (Table 5.12.1 extracted from IES Reference Handbook, 1987 provides some basic considerations and action plans.) (cont'd)

What to Consider	What Can Be Done in New Construction	What Can Be Done in Existing Spaces	Resource and Comments
7. Operating procedures a. During working hours b. During building cleaning periods.	In spaces with tasks, consider switching arrangements so that only general surround lighting can be used when tasks are not performed; however, it is important that an adequate illuminance be maintained for building cleaning. Allow for switching and switching ease to encourage turning lights off when not needed.	Analyze the lighting used during working and building cleaning periods. Institute an educational program to have workers turn off lights when they are not needed. Also have cleaners' schedules adjusted to minimize the lighting use, such as by cleaning fewer spaces at the same time, turning off lights in unoccupied areas.	
	Prepare a suggested lighting switching scheme, based on the design, to aid operations.	Where large floor or room areas are controlled by a single switch, consider adding more switching flexibility to turn off lights in areas when and where not needed.	

Table 5.12.1 Lighting Considerations and Ideas for Energy Management (Table 5.12.1 extracted from IES Reference Handbook, 1987 provides some basic considerations and action plans.) (cont'd)

What to Consider	What Can Be Done in New Construction	What Can Be Done in Existing Spaces	Resource and Comments
8. Space utilization	Where seeing task locations have not been specified, work with the office space planner to show locations where higher levels will occur to best take advantage of the lighting design and where daylighting can be used effectively. The use of open plan offices, when practical, increases room size and improves utilization of light. If new spaces is sparsely populated, consider locating employees with related work close together to efficiently provide the illumination needed for their tasks, and the remaining open area can be lighted to the lower level values for surrounding space and circulation areas.	Where it is found that workers are sparsely distributed consideration might be given to moving workers closer together and closing off unused space (with minimum heating, cooling and lighting). Also, an analysis of the existing lighting can show where tasks may be located to take advantage of the existing illumination provided and where veiling reflections are less.	

Table 5.12.1 Lighting Considerations and Ideas for Energy Management (Table 5.12.1 extracted from IES Reference Handbook, 1987 provides some basic considerations and action plans.) (cont'd)

STAGE II SURVEY

Equipment and Material required: A set of as–built plans, site plans, list of installed luminaires and their power ratings, inclusive of ballasts.

1. Introduction

The task here is to calculate the connected lighting load and, using occupancy schedules, to determine the annual energy budget.

The data collected may be used in the methods described in the Energy Performance Documents of this Series (D04 – D07) to run complete building energy analysis. The connected lighting load is defined as the Lighting Power Budget, while the energy lighting load is defined as the Lighting Energy Budget. The following is a detailed account of the procedures.

2. Procedure for Establishing Lighting Power Budget

.1 Complete attached forms LPB/1, and LPB/2, sheet 1 and 2 according to given instruction and insure that actual wattage loading so determined is within the guidelines shown in paragraph e. of the stage 1 survey of this appendix. LPB/1 only covers interior spaces, while LPB/2 covers building exteriors, roads and grounds and has summary tables for total building load. Tables 5.12.2 and 5.12.3 offer power budget values for common areas, indoor and outdoor, and can be used for preliminary estimates of power requirements.

.2 Spaces of similar size and illumination requirements need to be calculated only once.

.3 Spaces smaller than 14 m^2 can be optionally consolidated into an equivalent large space having equal illumination level.

.4 An example of using the Lighting Power Budget procedure is included with forms LPB/1 and LPB/2.

Areas and Function	Power Budget (watts per square metre)
General Office Area	24
Cafeteria	15
Parking Garages	2
Computer Rooms	18
Conference Room	14
Drafting	50
Laboratories	34
Health Facilities (examination and treatment rooms)	22
Boiler Room	7.53
Conference Room	13.99
Corridor	6.46
Electrical Equipment Room	6.46
Food Service Facilities	
Dining Areas	15.07
Kitchen	18.30
Garage, Parking	2.15
General Assembly (Auditorium)	11.84
Laboratories	34.44
Library Room	23.68
Lobby, Reception, Waiting	10.76
Locker Room and Shower	6.46
Mail Room	30.14
Material Handling (Bulk)	7.53
Mechanical Equipment Room	6.46
Stairs	6.46
Storerooms or Warehouse	
Inactive	2.15
Active Bulky	4.31
Active Medium	6.46
Switchboard and Control Room	18.30
Toilet and Washroom	7.53
Unlisted Spaces	2.15
Utility Room, General	4.31

Table 5.12.2 Lighting Power Budget for Interior Common Areas

Areas and Function	Power Budget (watts per linear metre)
Driveways	
Private (based on 2-lane width)	6.56
Public (based on 2-lane width)	9.84
Entrances With Canopy	
Decorative (Retail, Hotel, Theater, etc.)	107.64
Utilitarian (Hospital, Office, Ind., etc.)	43.06
Entrances Without Canopy	98.43
Exits, With or Without Canopy	65.62
Loading Area	3.23
Loading Doors	65.62
Outdoor Production and Processing	4.31
Outdoor Storage	2.15
Parking Lots (Open)	
Private	20.0
Public	30.0

Table 5.12.3 Lighting Power Budget for Exterior Areas

Workstation Type	Area Allowance
Secretary	5.50 m^2
Stenographer	4.00 m^2
Stenographer with Word Processing Equipment	5.50 m^2
Machine Operator	4.00 m^2
Designer/Draftsman	6.50 m^2
Clerk	4.00 m^2
Officer	7.25 m^2
Professional	7.25 m^2
Manager	10.00 m^2
Senior Manager	11.25 m^2

Table 5.12.4 Workstation Area Allowance

3. Form for Determining the Lighting Power Budget (Building Interior Data Sheet)
Refer to Form LPB/1

General — Identify the building and the project by filling in the top portion of the form.

Column 1 — Identify the workstation types which require the same illumination levels. Order them by their individual space allowance requirements. Thus combine all tasks having the same illumination and space requirements.

Column 2 — List illumination levels for each task group identified in column 1. (See Appendix 5.2 for required levels.)

Column 3 — List space allowance for individual task requirements of each group identified in column 1, using Table 5.12.4.

Column 4 — List for each group identified in column 1, the number of workstations requiring the same illumination level.

Column 5 — List the total space required by each group identified in column 1, by multiplying values in columns 3 and 4.

Column 6 — List type and manufacturer's luminaire description.

Column 7 — Calculate the luminaire coefficient of utilization from manufacturer's photometric data. Calculations as per IES Lighting Reference Handbook, 1984, Chapter 9.

Column 8 — List lamp efficacy using manufacturer's photometric data.

Column 9 — Calculate the Light Loss Factor.

Column 10 — Calculate for each workstation identified in column 1, the power budget requirements:

$$\frac{\text{Column 2 x Column 5}}{\text{Column 7 x Column 8 x Column 9}} = \text{Power Budget}$$

Column 11 — Calculate the total Room Power Budget by adding all values listed in column 10.

Column 12 — Enter any notation desired.

Note: — At the bottom of the page there is a total carry over to identify the total Power Budget for the project.

BUILDING IDENTIFICATION	NAME: ADDRESS: PROJECT NO.:										SHEET 1 of 1
1	2	3	4	5	6	7	8	9	10	11	12
Workstation Type with Illumination Level (Description)	Illumination Level (LUX)	Space Allowance			Luminaire Data				Workstation Power Budget [2] x [5] / [7] x [8] x [9] (Watts)	Total Room Lighting Power Budg. (Add All 10) (Watts)	Notes
		IND. SPACE ALLOW.	NO. WORKSTA. WITH	SAME ILLUM LEV.	Description (Type, Cat. #)	C.U.	Lamp Efficacy (lm/W)	LLF			
TOTALS THIS PAGE											
								TOTAL PREVIOUS PAGE			
								PROJECT TOTAL			

LPB/1 FORM FOR CALCULATING LIGHTING POWER BUDGET (BUILDING INTERIORS)

4. Form for Determining the Lighting Power Budget (Summary of Building Interiors, Building Exteriors and Grounds and Total Project)

Refer to Form LPB/2, Sheet 1 and Sheet 2

1. Summary of Building Interiors

General — Identify the building and the project by filling in the top portion of the form.

Line 1 — Identify the gross building floor area, using the outside dimensions shown on drawings.

Line 2 — Identify the total area of all listed interior spaces by entering total value from column 5, LPB/1.

Line 3 — Identify the total area of all unlisted interior spaces by subtracting line 2 from line 1.

Line 4 — Calculate Power Budget for UNLISTED SPACE:

2.15 W/m² x line 3

Line 5 — Calculate Power Budget for LISTED SPACE:

Total of column 11 of LPB/1.

Line 6 — Calculate Power Budget for BUILDING INTERIOR:

Sum lines 4 and 5

Line 7 — Calculate Power Budget unit power density (in W/m²):

Divide line 6 by line 1

2. Summary of Building Exteriors

Line 8 — Calculate supplementary and facade lighting allowed (5% of line 5).

Line 9 — Calculate area of building entries with canopies.

Line 10 — Calculate Power Budget for line 9 (107.6 W/lin m) therefore 107.6 x line 9.

Line 11 — Calculate total width of building entries without canopies.

Line 12 — Calculate Power Budget for line 11
(98.4 W/lin m)
Therefore 98.4 x line 11.

Line 13 — Calculate the total width of all building exits and loading doors.

Line 14 — Calculate Power Budget for line 13
(65.6 W/lin m)
Therefore 65.6 x line 13.

Line 15 Calculate the total Building Exterior Power Budget by adding lines 8, 10, 12, 14.

3. Summary of Exterior Roads and Grounds

Line 16 Enter number of exterior parking stalls.

Line 17 Enter Power Budget for line 16:

Private Parking = 20 W x No. of Stalls
Public Parking = 30 W x No. of Stalls.

Line 18 Enter length of 2 lane feeder road.

Line 19 Enter Power Budget for line 18:

Private Road = 6.5 W x Length of Road
Public Road = 9.8 W x Length of Road.

Line 20 Enter outdoor work areas requiring illumination.

Line 21 Enter Power Budget for line 20:

4.3 W x Surface Area (m^2)

Line 22 Enter outdoor storage area.

Line 23 Enter Power Budget for line 22:

2.15 W x Surface Area (m^2).

Line 24 Enter Power Budget for total grounds and roads by adding lines 17, 19, 21, 23.

4. Summary of Total Project

Line 25 Enter Power Budget for total building (interior, exterior) by adding lines 6, 15.

Line 26 Enter Power Budget unit power density (in W/m^2):

Divide line 25 by line 1.

Line 27 Enter Power Budget for Total Project:

Add lines 6, 15, 24.

BUILDING IDENTIFICATION	NAME: _____ ADDRESS: _____ PROJECT NO.: _____	PAGE 1 of 2

PART 1. SUMMARY OF BUILDING INTERIORS

LINE	ITEM	POWER (W)	AREA M(²)	GUIDE	NOTES
1	Gross Building Floor Area			Exterior Building Size	
2	Total Area of Listed Interior Spaces			Total of Column [5]. LPB/1	
3	Unlisted (Net) Building Area			[1] - [2]	
4	Power Budget: Unlisted Space			2.15 W/m² X [3]	
5	Power Budget: Listed Space			Total of Column [11]. LPB/1	
6	Power Budget: Building Interior			[4] + [5]	
7	Power Budget: Unit Power Density			[6] ÷ [1] (W/m²)	

PART 2. SUMMARY OF BUILDING EXTERIORS

LINE	ITEM	POWER (W)	AREA OR LENGTH	GUIDE	NOTES
8	Supplementary and Facade Lighting			5% of [5]	
9	Building Entries With Canopies			Total Width of Exterior Areas Under Canopies(m)	
10	Power Budget: Entries With Canopies			107.6 W/m x [9]	
11	Building Entries Without Canopies			Total Width (m)	
12	Power Budget: Entries Without Canopies			98.4 W/m x [11]	
13	Building Exits and Loading Doors			Total Width (m)	
14	Power Budget: Exits and Loading Doors			65.6 W/m x [13]	
15	Power Budget: Total Building Exterior			Add [8]. [10]. [12]. [14]	

LPB 2. FORM FOR CALCULATING LIGHTING POWER BUDGET (BUILDING INTERIORS AND EXTERIORS

BUILDING IDENTIFICATION	NAME: _____ ADDRESS: _____ PROJECT NO.: _____ PAGE 2 of 2

PART 3. SUMMARY OF ROADS AND GROUNDS

LINE	ITEM	POWER (W)	QUANTITY AREA OR LENGTH	GUIDE	NOTES
16	Number of Exterior Parking Stalls			Quantity, Not Area	
17	Power Budget: Exterior Parking			Private: 20 W x [16] Public: 30 W x [16]	
18	Length of 2 Lane, Feeder Roadways			Total Length (m)	
19	Power Budget: Feeder Roadways			Private: 6.5 W/m x [18] Public: 9.8 W/m x [18]	
20	Total Area Exterior Processing			m^2	
21	Power Budget: Processing			4.3 W/m^2 x [20]	
22	Total Area: Exterior Storage Yards			m^2	
23	Power Budget: Exterior Storage Yards			2.15 W/m^2 x [22]	
24	Power Budget: Total Road and Grounds			Add [17], [19], [21], [23]	

PART 4. SUMMARY OF TOTAL PROJECT

LINE	ITEM	POWER (W)	UNIT POWER DENSITY (W/m^2)	GUIDE	NOTES
25	Power Budget: Total Building			Add [6], [15]	
26	Power Budget: Total Unit Power Density			25 ÷ [1] (W/m)	
27	Power Budget: Total Project			Add [6], [15], [24]	

LPB 2. FORM FOR CALCULATING LIGHTING POWER BUDGET (BUILDING INTERIORS AND EXTERIORS) (cont'd)

4. Determination of the Lighting Energy Budget

1. Refer to Form LPB2, line 1 "Gross Building Floor Area" and multiply this value by 68 to obtain maximum annual energy budget limit for the building (from example: 68 x 376 = 25,568 kWh/yr).

2. Refer to form LPB2, line 7 "Unit Power Density" and multiply this value by 3.12 to obtain maximum installed annual energy consumption per unit area (from example: 3.12 x 10.7 = 33.4 kWh/m²/yr).

3. Take unitary energy consumption from 2. above and multiply it by total building area shown in line 1 to obtain "Total maximum installed annual energy consumption (from example: 33.4 x 376 = 12,558 kWh/yr).

4. Compare actual annual energy consumption with maximum permissible values, from 1. above (from example: 12,558 kWh/yr vs 25,568 kWh/yr).

5. Refer to line 15 "Total Building Exterior" and multiply this value by 3.64 to obtain maximum annual energy budget limit for the Building Exteriors (from example: 1,349 x 3.64 = 4,910 kWh/yr).

6. Physically survey the Building Exteriors (excluding roads, parking, and grounds) and analyze annual time scheduling to arrive at actual energy consumption. This value should not exceed the one found in 5. above.

7. Repeat the same process indicated in 5. and 6. for the balance of Exterior Lighting Loads.

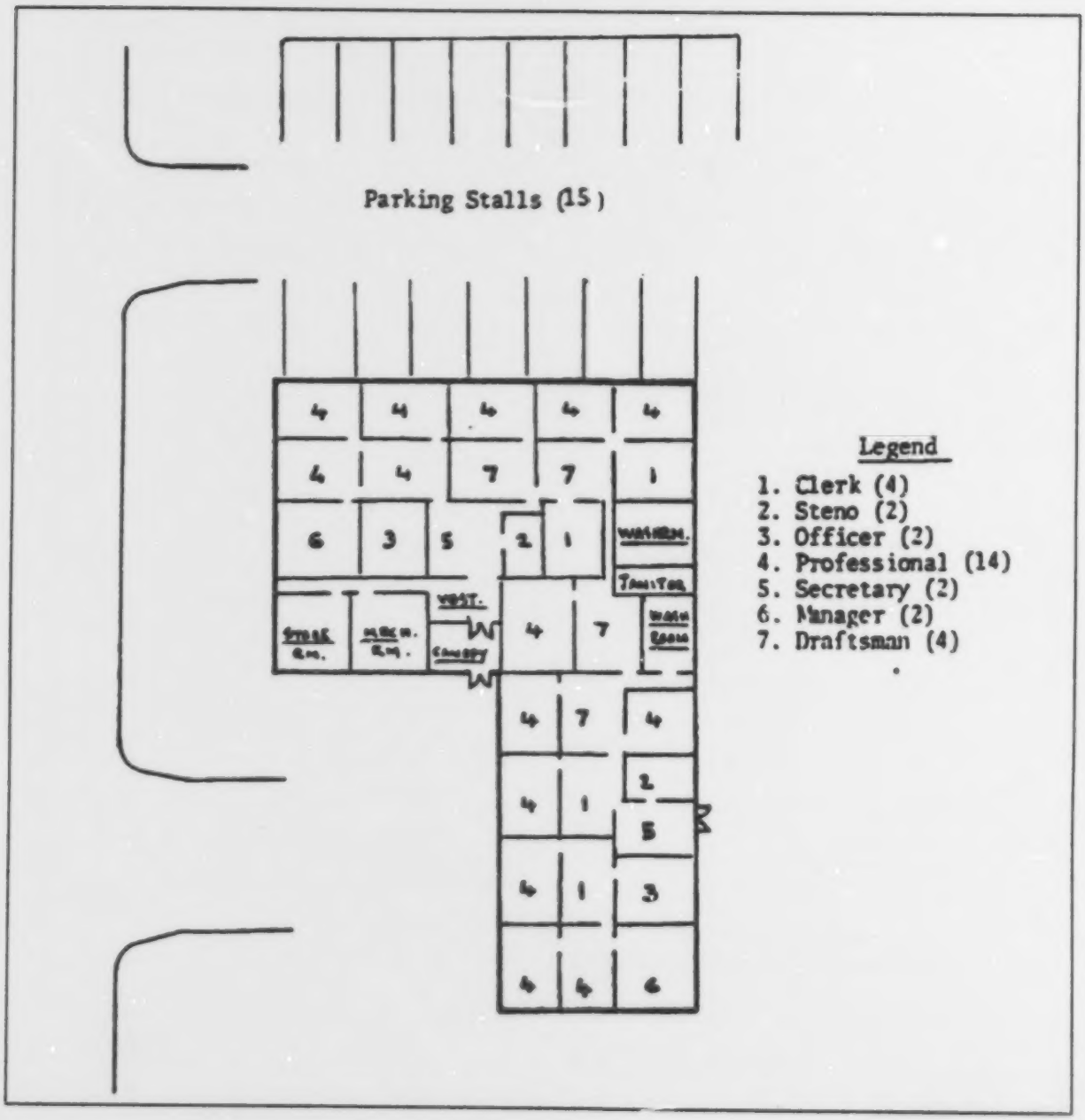


Figure 5.12.1 Example Building: Lighting Power Budget Calculation

BUILDING IDENTIFICATION	NAME: _____ ADDRESS: _____ PROJECT NO.: _____										SHEET 1 of 1
	2	3	4	5	6	7	8	9	10	11	12
Workstation Type with Illumination Level (Description)	Illumination Level (LUX)	Space Allowance m²	#	3 x 4	Luminaire Data Description (Type, Cat. #)	C.U.	Lamp Efficacy (lm/W)	LLF	Workstation Power Budget [2] x [5] [7] x [8] x [9] (Watts)	Total Room Lighting Power Budg. (Add All 10) (Watts)	Notes
Steno. Clerk	500	4.0	6	24	X, Y, Z	0.72	78	0.72	297		
Officer, Prof.	500	7.25	16	116	X, Y, Z	0.72	78	0.72	1434		
Manager	750	10.0	2	20	X, Y, Z	0.72	78	0.72	371		
Secretary	750	5.5	2	11	X, Y, Z	0.72	78	0.72	204		
Draftsman	1,000	6.5	4	26	X, Y, Z	0.72	78	0.72	643		
Gen. Lighting	300	4.0	15	60	X, Y, Z	0.72	78	0.72	445		
Vestibule	300	4.0	1	4	X, Y, Z	0.50	78	0.72	43		
Janitor	200	3.0	1	3	X, Y, Z	0.50	78	0.72	21		
Storage	100	7.0	1	7	X, Y, Z	0.50	78	0.72	25		
Washroom	300	15.0	1	15	X, Y, Z	0.50	78	0.72	160		
Washroom	300	10.0	1	10	X, Y, Z	0.50	78	0.72	107		
Corridor	300	10.0	1	10	X, Y, Z	0.50	78	0.72	107		
TOTALS THIS PAGE		306								3,857	
								TOTAL PREVIOUS PAGE		3,857	
								PROJECT TOTAL		3,857	

EXAMPLE

LPB/1 **FORM FOR CALCULATING LIGHTING POWER BUDGET (BUILDING INTERIORS)**

BUILDING IDENTIFICATION	NAME: _____ ADDRESS: _____ PROJECT NO.: _____	PAGE 1 of 2

PART 1. SUMMARY OF BUILDING INTERIORS

LINE	ITEM	POWER (W)	AREA M(²)	GUIDE	NOTES
1	Gross Building Floor Area		376	Exterior Building Size	
2	Total Area of Listed Interior Spaces		306	Total of Column [5], LPB/1	
3	Unlisted (Net) Building Area		70	[1] - [2]	
4	Power Budget: Unlisted Space	150		2.15 W/m² X [3]	
5	Power Budget: Listed Space	3,857		Total of Column [11], LPB/1	
6	Power Budget: Building Interior	4,007		[4] + [5]	
7	Power Budget: Unit Power Density	10.7		[6] ÷ [1] (W/m²)	

PART 2. SUMMARY OF BUILDING EXTERIORS

LINE	ITEM	POWER (W)	AREA OR LENGTH	GUIDE	NOTES
8	Supplementary and Facade Lighting	193		5% of [5]	
9	Building Entries With Canopies		8	Total Width of Exterior Areas Under Canopies(m)	
10	Power Budget: Entries With Canopies	861		107.6 W/m x [9]	
11	Building Entries Without Canopies		3	Total Width (m)	
12	Power Budget: Entries Without Canopies	295		98.4 W/m x [11]	
13	Building Exits and Loading Doors		-	Total Width (m)	
14	Power Budget: Building Exits and Loading Doors	-		65.6 W/m x [13]	
15	Power Budget: Total Building Exterior	1,349		Add [8], [10], [12], [14]	

EXAMPLE

LPB 2. FORM FOR CALCULATING LIGHTING POWER BUDGET (BUILDING INTERIORS AND EXTERIORS

BUILDING IDENTIFICATION	NAME: _____ ADDRESS: _____ PROJECT NO.: _____	PAGE 2 of 2

PART 3. SUMMARY OF ROADS AND GROUNDS

LINE	ITEM	POWER (W)	QUANTITY AREA OR LENGTH	GUIDE	NOTES
16	Number of Exterior Parking Stalls		15	Quantity, Not Area	
17	Power Budget: Exterior Parking	300		Private: 20 W x [16] Public: 30 W x [16]	
18	Length of 2 Lane, Feeder Roadways		200	Total Length (m)	
19	Power Budget: Feeder Roadways	1,300		Private: 6.5 W/m x [18] Public: 9.8 W/m x [18]	
20	Total Area Exterior Processing		0	m^2	
21	Power Budget: Exterior Processing	0		4.3 W/m^2 x [20]	
22	Total Area: Exterior Storage Yards		0	m^2	
23	Power Budget: Exterior Storage Yards	0		2.15 W/m^2 x [22]	
24	Power Budget: Total Road and Grounds	1,600		Add [17], [19], [21], [23]	

PART 4. SUMMARY OF TOTAL PROJECT

LINE	ITEM	POWER (W)	UNIT POWER DENSITY (W/m^2)	GUIDE	NOTES
25	Power Budget: Total Building	5,356		Add [6], [15]	
26	Power Budget: Total Unit Power Density		14.2	25 ÷ [1] (W/m)	
27	Power Budget: Total Project	6,956		Add [6], [15], [24]	

EXAMPLE

LPB 2. **FORM FOR CALCULATING LIGHTING POWER BUDGET (BUILDING INTERIORS AND EXTERIORS)** (cont'd)

STAGE III SURVEY

1. This level of survey is required only for pilot projects, where it is desirable to create a reference data bank on various types of energy management strategies, fully integrated with all building systems. Many and varied are the approaches available, however the following points are of common concern:

   a. identification of basic luminaire and building data as provided by Stage I and II;

   b. identification of building occupancy profile, done using a combination of information provided by management, personal observations, and data collected through the use of occupancy sensors and light load sensors. Questionnaires may also be considered;

   c. identification of complete lighting control operations and related data for the purpose of identifying mismatches, needs of calibration or integration with other building systems or elements, opportunities for improvements in both size of controlled zone and quality of control;

   d. identification of annual costs, complete study of the environmental impact on lighting quantity, quality and energy consumption, impact on HVAC system(s), and impact on maintenance procedures and costs;

   e. identification of opportunities for improving total building performance in environmental lighting, thermal, and acoustic issues, as well as opportunities to optimize the technical and economic performance of the lighting system.

2. Specific step–by–step procedures are not suggested because of their complexity.

   Specialized multi–disciplinary team efforts are required to successfully complete this stage. Advice and help can be obtained by contacting PWC Headquarters.

5.13 LIGHTING MAINTENANCE SURVEYS

Proper lighting maintenance is an essential component in maintaining a well performing luminous environment. In addition to the usual manufacturer's maintenance requirements to validate equipment warranties, there is the added legal requirement under the Labour Canada Regulations (COSH) to maintain minimum levels of lighting (see Appendix 5.2). Finally it is false economy to reduce those maintenance level requirements established at the design stage, if this may result in a very small reduction in employees' performance. In fact it only takes one to two hours of salary to offset an employee's yearly lighting costs.

STAGE I AND II: MAINTENANCE SURVEY

Equipment and material required: temperature probe, electric multi-meter, maintenance logs, manual/automatic operation log, as-built drawings, manufacturers luminaire data.

This consists of a field walkthrough to visually assess the level of lighting systems maintenance. It ranges from the complete luminaire, and its control mechanism, to physical and environmental conditions directly impacting on lighting maintenance. The following are suggested steps:

- obtain a list of all installed luminaires and their characteristics;
- obtain a record of maintenance practices and a log of malfunctions;
- determine hours of operation for all lighting systems (see Note 1).
- enquire if maintenance programs are set according to manufacturers recommendations for each type of light source (see Note 2).
- note evidence of dirt and yellowing on lenses and in luminaires;
- note lense sagging;
- note luminaire failure and determine causes;
- note evidence of de-lamping, re-lamping, retrofitting, relocations, shading of glare sources, additional task lighting and the like;
- note deterioration of ambient reflectances (see Appendix 5.3 and 5.5 for reference values and measurement techniques);
- note operability and adequacy of lighting control devices (local and remote, manual and automatic);
- note evidence of problems with luminaire aiming, mounting and focussing (if applicable);
- note evidence of ballasting problems (overheating, leaking, noisy, improperly located);
- note evidence of utilization of very dark or bright surfaces and evidence of poor surface reflectance due to lack of upkeep;
- from all of the above formulate alternative appropriate lighting maintenance procedures which optimizes performance and economic return. Computer programs are available from PWC/HQ – Ottawa to help in this selection process.

NOTES:

1. Hours of operation are determined by estimating cyclical operation requirements of various lighting loads and their utilization factor as a percentage

of full load. Spot surveys, coupled with operation requirements, provided by building operators and maintenance personnel, provide a fair estimate of lighting operations for both indoor and outdoor cases. Better estimates can only be provided if a lighting usage monitor, as developed by NRCC, is in use for each zone.

2. Referring to manufacturer's recommended maintenance practices, note if the following precautions are exercised:

   a. overwattage relamping avoided (unless required by design);
   b. quartz–halogen lamps never handled with bare hands and, if on dimmers, operated at full output from time–to–time to re–establish halogen cycle;
   c. metal–halide lamps generally enclosed in a CSA approved luminaire. Check for their suitability to be operated with or without a protective lens with the manufacturer, e.g. there are several variations;
   d. relamping of HPS lamps shortly after they begin to display cycling or very monochromatic yellow colour tones.

Figure 5.13.1 shows typical light loss values for a fluorescent light system. Estimates of standard F40 fluorescent lamp failure rates and their typical ballasts are shown in Tables 5.13.1 and 5.13.2.

Table 5.13.3 shows recommended cleaning compounds

Table 5.13.4 shows recommended trouble shooting practices

Information contained in Figure 5.13.1, Tables 5.13.1 and 5.13.2 are derived from IES Application Volume, Section 4, 1987.

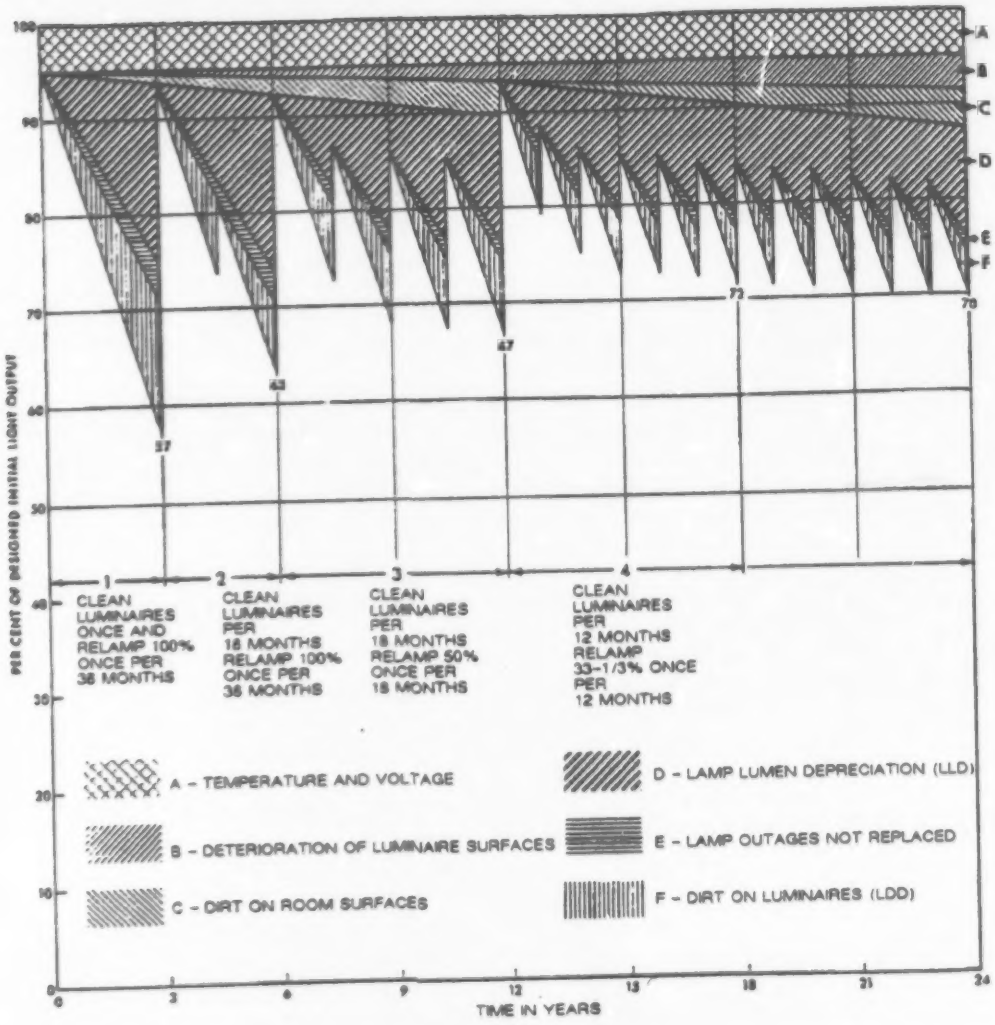

PER CENT OF ORIGINAL INITIAL LIGHT OUTPUT
TIME IN YEARS
A
B
C
D
E
F
1
CLEAN LUMINAIRES ONCE AND RELAMP 100% ONCE PER 36 MONTHS
2
CLEAN LUMINAIRES PER 18 MONTHS RELAMP 100% ONCE PER 36 MONTHS
3
CLEAN LUMINAIRES PER 18 MONTHS RELAMP 50% ONCE PER 18 MONTHS
4
CLEAN LUMINAIRES PER 12 MONTHS RELAMP 33-1/3% ONCE PER 12 MONTHS
A - TEMPERATURE AND VOLTAGE
B - DETERIORATION OF LUMINAIRE SURFACES
C - DIRT ON ROOM SURFACES
D - LAMP LUMEN DEPRECIATION (LLD)
E - LAMP OUTAGES NOT REPLACED
F - DIRT ON LUMINAIRES (LDD)

Figure 5.13.1 Typical Light Loss Values for a Fluorescent Light System

Example above used 40-watt T-12 cool white rapid start lamps in enclosed surface mounted units, operated 10 hours per day, 5 days per week, 2,600 hours per year. All four maintenance systems are shown on the same graph for convenience. For a relative comparison of the four systems, each should begin at the same time and cover the same period of time.

MONTH	ACCUMULATED HOURS OF USE	% LAMP FAILURES	% OF RATED LAMP LIFE CONSUMED
0	0.0	0.0	0.0
3	912.5	0.0	0.038
6	1,825.0	0.0	0.076
9	2,737.5	0.0	0.114
12	3,650.0	0.0	0.152
15	4,562.5	0.0	0.190
18	5,457.0	0.0	0.227
21	6,387.5	0.1	0.266
24	7,300.0	0.1	0.304
27	8,212.5	0.3	0.342
30	9,125.0	0.5	0.380
33	10,037.5	1.0	0.418
36	10,950.0	1.7	0.456
39	11,862.5	2.9	0.494
42	12,775.0	4.7	0.532
45	13,687.5	7.3	0.570
48	14,600.0	10.7	0.608
51	15,512.5	15.2	0.646
54	16,425.0	20.7	0.684
57	17,337.5	27.2	0.722
60	18,250.0	34.5	0.760

Table 5.13.1 Typical Failure Rates for F40 Fluorescent Lamps Operated for 3,650 Hours/Year

YEAR	FAILURES PER YEAR
1	0.3
2	0.5
3	1.0
4	1.6
5	2.9
6	4.5
7	6.8
8	9.5
9	11.3
10	12.0
11	12.5
12	12.0
13	11.3
14	9.7
15	8.7
16	8.2
17	7.8
18	8.4
19	8.9
20	9.4
22	10.2
23	10.2
24	10.2
25	9.8

Table 5.13.2 Typical Ballast Failure Rate When Operated 4,000 Hours/Year

Aluminum. Very mild soaps and cleaners can be used on aluminum and will not affect the finish, if the material is thoroughly rinsed with clean water immediately after cleaning. Strong alkaline cleaners should never be used.

Porcelain Enamel. This finish is not injured by non–abrasive cleaners. Detergents and most automobile and glass cleaners do a good job under average conditions.

Synthetic Enamel. Some strong cleaners may injure this finish: particularly in cases where the enamel is left to soak in the solution. Alcohol or abrasive cleaners should not be used. Detergents produce no harmful effects.

Glass. As with porcelain enamel, most non–abrasive cleaners can be used satisfactorily on glass. Dry cleaners are usually preferred on clear glass panels, but not on etched or sand blasted surfaces. Most detergents will work well under average conditions.

Plastics. Very often dust is attracted by a static charge developing on plastic. Most common detergents do not provide a high degree of permanence in their anti–static protection. In most areas, however, if the plastic is cleaned at least twice a year with a detergent, a satisfactory relief from static dirt collection is obtained. Destaticizers are available which have greater permanence than common detergents in this respect. Plastic should not be wiped dry after the application of a rinse solution.

Table 5.13.3 Recommended Cleaning Agents for Lighting Maintenance

Incandescent Lamps.

Maintenance Hints. Troubles with incandescent lamps are usually the result of misapplication, improper operating conditions or poor maintenance practice. Most problems can be avoided by applying the following maintenance hints:

1. *Over–voltage or over–current operation.* Rating of lamps should correspond with actual circuit operating conditions. Over–voltage or over–current operation may shorten lamp life drastically. For example, a 120–volt lamp operated on a 125–volt circuit suffers a 40 percent loss in life.

2. *Shock and vibration conditions.* Under such conditions, the use of vibration service or rough service lamps is recommended. The use of general service lamps under these conditions results in short life.

3. *Sockets.* Lamps of higher wattage should not be operated in sockets designed for a specified wattage or excessive lamp and socket temperatures may result. Excessive temperatures may affect lamp performance or may shorten the life of insulated wire, sockets, etc.

Table 5.13.4 Trouble Shooting Lighting Systems

4. *Luminaires.* Only the proper lamps for which the luminaire was designed should be used. Contact of any metal part of a luminaire with a hot lamp may result in violent failure of the lamp.

5. *Cleaning lamps.* A wet cloth should not be used to clean a hot lamp. A violent failure may occur with a wet cloth.

6. *Proper burning position.* Lamps should be operated in their proper burning position as specified by the lamp manufacturer. Operation of the lamps in the wrong position may cause a lamp to fail immediately or after short life.

7. *Replacing lamps.* Whenever possible, lamps should be replaced with power "off". Replacing lamps with power "on", particularly high voltage types, can result in the drawing of an arc between the lamp base and the socket.

8. *Tungsten–halogen lamps.* Lamps should be installed with the power "off". It is also recommended that the bulb be held with a clean cloth or tissue to avoid fingerprints on the bulb. Fingerprints may result in bulb discoloration and a subsequent reduction in light output. Follow lamp manufacturers' instructions on the carton of each lamp.

9. *Dichroic reflector lamps.* Certain lamps utilize a dichroic reflector designed to radiate heat back through the reflector portion of the bulb. Luminaires using these lamps should be ventilated, or other wise designed to provide adequate cooling of the socket and wiring adjacent to the bulb.

Preheat Starting Fluorescent Lamp Circuits.

Trouble Shooting.

1. Replace existing lamps with lamps known to be operative.

2. Check to make certain lamps can be used on preheat circuits. Use only lamp types marked on ballast labels.

3. Replace existing starters with starters known to be operative. No blink type starters are recommended for replacement.

4. Check luminaire wiring for incorrect connections, loose connections or broken wires. Refer to the wiring diagram printed on the ballast.

5. Check ballast to see if the label agrees with the application in terms of temperature limitations and lamps that can be used. Replace ballast if faulty or does not fit application requirements.

Table 5.13.4 Trouble Shooting Lighting Systems (cont'd)

Maintenance Hints.

1. Deactivated lamps should be replaced as quickly as possible. Blinking lamps cause abnormal currents to flow in the ballast which will cause ballast heating and thereby reduce ballast life.

2. Blinking lamps will also reduce starter life.

3. Energy saving 30– and 40–watt rapid start lamps should not be used on preheat starting fluorescent circuits. Replace with standard lamps.

Rapid Starting Fluorescent Lamp Circuits.

Trouble Shooting. Constant heater current is essential for proper starting of all rapid start type lamps. For 800 mA and 1500 mA types, the constant heater current is also essential for proper lamp operation.

1. If lamp requires 5 or 6 seconds to start, one cathode is probably not receiving the cathode heating current. This usually results in excessive end darkening of the end not receiving cathode heat after a short period of operation. With lamps out of the sockets, check heater voltages. This can be done with available testers which have a flashlight lamp mounted on a fluorescent lamp base. If a voltmeter is used, a 10–ohm, 10–watt resistor should be inserted in parallel with the meter. The meter should measure at least 3 volts. If proper voltage is available, check for poor contact between lampholder and base pins or contacts on the lamp. If no voltage is measured, check for open circuit (poor or improper connections, broken or grounded wires, open heater circuit on the ballast). Check for proper spacing of lampholders.

2. If one lamp is out and the other lamp is operating at low brightness or if both lamps are out, only one lamp may be deactivated.

3. Replace the ballast if wrong or no voltage is supplied to the lamps after determining output voltage to the ballast is correct.

Maintenance Hints.

1. Deactivated lamps should be replaced as quickly as possible. The 800 mA and 1500 mA lamps require both heater current and operating current for proper operation. If either is missing, poor starting or short lamp life will result. In the 2–lamp series circuit, one lamp can fail and the second lamp will operate at reduced current. This condition will reduce the life of the second lamp.

Table 5.13.4 Trouble Shooting Lighting Systems (cont'd)

2. Lamps should be kept reasonably clean. The bulbs of all rapid start type lamps are coated with a silicone to provide reliable starting in conditions of high humidity. Dirt can collect on the lamp surface which could absorb moisture in high humidity atmospheres, thus nullifying the silicone coating, and prevent starting or cause erratic starting.

Instant Starting Fluorescent Lamp Circuits.

Trouble Shooting. Note that 2-lamp circuits can be either lead-lag or series-sequence design.

1. Replace existing lamps with lamps known to be operative.

2. Check lampholders for broken or burned contacts or discolored plastic in the holders, indicating high temperature. Check circuit for improper or broken wires. Refer to wiring diagram on the ballast.

3. If ballast is suspected of being defective, replace with ballast known to be operative. Measurement of ballast voltages in the luminaire is difficult because the primary circuit of the ballast is automatically disconnected when a lamp is removed.

Maintenance Hints.

Deactivated lamps should be replaced as soon as possible. In the 2-lamp series circuit, one lamp can fail and the second lamp will operate at low brightness. This condition will reduce the life of the second lamp and also will cause an abnormal current to flow in the ballast, giving rise to ballast heating and a reduction in ballast life.

Mercury Lamps.

Trouble Shooting.

1. Replace lamp with lamp known to be operative. Be sure operative lamp is cool as hot lamps will not restart immediately.

2. Check that lamp is properly seated and that the lamp's base eyelet and shell make proper contact in the lampholder.

3. Check ballast nameplate. Make sure that ballast and lamp designations match. Refer to the system of lamp/ballast designations developed by the lamp industry and American National Standards Institute.

4. Check ballast wiring. If a tapped primary winding ballast is used, be sure the connected tap matches the available supply voltage.

5. Check supply circuit wiring for open circuit or incorrect connections.

Table 5.13.4 Trouble Shooting Lighting Systems (cont'd)

6. Replace ballast if no output voltage can be obtained and line voltage is properly connected to ballast input terminals.

7. If a lamp fails prematurely or if lamps continue to fail prematurely in a similar failure mode in the same luminaire, check for the following:

   a. *Lamp breakage* – outer envelope cracks or breakage will allow air to enter the lamp and cause arc tube seal failure. Cracks or breakage can be caused by rough handling, by contact with metal surfaces of a bulb changer or metal parts of the luminaire or by water droplets falling on an operating lamp.

   b. *Excessively black or swollen arc tubes* – may indicate excessive lamp current and over–wattage operation. See 3, 4, and 5 above. Also the ballast may have failed due to a component failure, such as a capacitor or shorted core wiring.

   Caution: To prevent electric shock hazard always turn off power before removing or installing lamps. This is especially important when removing lamps that may have cracked or broken outer envelopes. Unless power is turned off, the exposed metal parts of the internal lamp structure will be connected and touching them may cause an electric shock.

Maintenance Hints.

1. If tapped ballasts are used, check should be made to be sure that tap matches supply voltage to which the ballast tap is connected. Connecting a *given* line voltage to a *higher* marked tap will give *low* light output due to under–wattage operation. Connecting a *given* line voltage to a *lower* marked tap will cause poor lumen maintenance and short life due to over–wattage operation.

2. The line voltage should be reasonably free of voltage fluctuations. A variety of ballast types that provide a desired percentage lamp wattage regulation with respect to percentage line voltage variation are available.

3. Lamp and ballast combinations must be chosen so that their electrical characteristics match. This can be assured by following the system of lamp and ballast designation developed by the lamp industry and ANSI. Incorrect lamp and ballast matching may result in short life and equipment damage.

4. Lamps should be handled carefully. Rough handling can cause scratches or cracks in outer glass envelopes resulting in short lamp life and possible injury.

Caution: If the outer envelope of a lamp is broken or punctured, the arc tube will continue to burn for many hours. Unless the luminaire is shielded, ultraviolet radiation will be emitted to the surrounding area. Certain types of lamps that will automatically extinguish if the outer envelope is broken or punctured are available.

Table 5.13.4 Trouble Shooting Lighting Systems (cont'd)

Self-Ballasted Mercury Lamps.

Trouble Shooting.

1. Items 1, 2, 5, and *Caution* listed for mercury lamps apply.

2. Self-ballasted lamps are rated by voltage. They should be used in installations in which available socket voltages correspond to the allowed voltage range recommended by the manufacturer for the particular lamp.

3. In general, self-ballasted mercury lamps take longer than mercury lamps, but less than metal halide lamps, to automatically restart after a short power interruption.

4. Lamps rated for 120-volt line voltage operation are constructed with an internal thermostatic switch to preheat the arc tube starting electrode(s). The action of the switch may result in a "blinking" during lamp starting and restarting. The "blinking" will occur in about 7 to 30 seconds after the lamp is energized and in less than that time during the automatic restarting.

5. Starting temperature limits published by the manufacturers should be carefully followed. Since these lamps operate directly from the available line voltage, no "set up" voltage can be introduced as is the case for mercury, metal halide and high pressure sodium lamps where ballasts must be used and step up transformers can be incorporated.

Maintenance Hints.

1. Lamps should be handled carefully. Rough handling can cause scratches or cracks resulting in short life and possible injury.

2. As self-ballasted mercury lamps are likely to be replaced into existing incandescent sockets, lamps will be installed in old luminaires. Rating of socket should not be exceeded and water falling on bulb must be prevented. Follow manufacturers' recommendations for indoor and outdoor burning positions in open and closed luminaires.

Metal Halide Lamps.

Follow recommendations and all *Cautionary measures* given for mercury lamps as these also apply to metal halide lamps; however, the following additional information is pertinent:

Table 5.13.4 Trouble Shooting Lighting Systems (cont'd)

Trouble Shooting.

1. Many metal halide lamps are to be used only in identified operating positions. Short life and improper light and color output will result if lamps are not used in their recommended burning positions.

2. Time to automatically restart after a short power interruption may be much longer than for mercury lamps. This is not a lamp defect and should not mean that a lamp should be replaced.

3. It is possible for metal halide lamps to have a short delay between the time that the circuit is energized and the lamp starts.

4. It is a characteristic of metal halide lamps that slight source color shifts from lamp to lamp can exist. Also, one to two days of burning in an installation may be required to stabilize the color of the lamps.

Caution: Follow lamp manufacturers' recommendations with respect to metal halide lamp allowed use in open or enclosed luminaires.

Maintenance Hints.

1. If a metal halide lamp is to be moved from one luminaire to another, transfer the lamp by keeping it in the position in which it was installed.Changing position of even a cool lamp will require re-stabilization time with respect to color.

2. Only operate metal halide lamps in their allowed operating positions.

Low Pressure Sodium Lamps

Trouble Shooting.

1. Replace lamp with lamp known to be operative.

2. Check lampholder for proper seating of the lamp and for proper contact.

3. Check ballast nameplate reading.

4. Check ballast wiring. If a tapped ballast is used, be sure ballast tap matches supply voltage at the ballast.

5. Check circuit wiring for open circuit or incorrect connections.

6. Check grounding of luminaires.

7. Replace ballast.

Table 5.13.4 Trouble Shooting Lighting Systems (cont'd)

8. If lamps fail prematurely, check for the following:

   a. Lamp breakage. Check lamps for cracks or scratches in the outer bulb. These can be caused by rough handling, by contact with metal surfaces in bulb changer or luminaire, or by moisture falling on overheated bulb.

   b. Bulb touching the luminaire, the lampholder or other hard surface.

9. If arc tube is cracked, blackened or swollen early in life, or if connecting leads inside outer bulb are damaged, check for the following:

   a. *Over–wattage operation*. Check the ballast rating and the voltage at the ballast and if proper tap on ballast is used.

   b. *Excessive current*. Check if ballast is shorted. Check for possible voltage surges or transients on the supply line.

Caution: Do not replace with new bulb until circuit is checked and cause of trouble has been corrected.

Maintenance Hints.

1. If tapped ballasts are used, check should be made to be sure tap matches supply voltage at ballast. Low voltage will cause low light output, poor lumen maintenance and reduced lamp life. High voltage will cause short lamp life.

2. The circuit should be reasonably free from voltage fluctuations. Replacement ballasts should match the particular voltage, frequency and lamp type.

3. The proper lamp type should be used for the ballast in installation. Incorrect matching of lamp and ballast may result in short lamp life or lamps going on and off repeatedly.

4. Lamps should be handled carefully to avoid breakage.

High Pressure Sodium Lamps.

Trouble Shooting

1. Follow steps 1 through 6 listed for mercury lamps.

2. If lamp fails prematurely or if lamps continue to fail prematurely in a similar luminaire mode or in the same luminaire, check the following:

   a. Same as 7a under mercury lamps.

Table 5.13.4 Trouble Shooting Lighting Systems (cont'd)

b. Excessive discoloration of the arc tube or a metallic deposit on the inside walls of the outer envelope may indicate over-wattage operation. See 3, 4, and 5 under Trouble Shooting for mercury lamps. Also, ballast components may have failed, such as a shorted capacitor or shorted core windings.

3. High pressure sodium lamps require an ignitor to start the lamp. If lamp does not start and a known good lamp does not start either, steps must be taken to determine if the ignitor or the ballast or perhaps both are defective. First make certain that the proper line voltage is correctly connected to the ballast input. Obtain a ballast tester from a ballast manufacturer and follow instructions on the tester to determine the defect.

Maintenance Hints.

1. Follow steps 1 through 4 listed for mercury lamps.

2. High pressure sodium lamps have a vacuum in the space between the ceramic arc tube and the outer envelope. Handle these lamps carefully since vacuum lamps make a loud noise if dropped and if the glass should break.

3. In case of outer envelope breaking during lamp operation, ultraviolet emission is *not* a problem.

Caution: To prevent electric shock hazard always turn off power before removing or installing lamps. This is especially important when removing lamps that may have cracked or broken outer envelopes. Unless power is turned off, the exposed metal parts of the internal lamp structure will be connected and touching them may cause an electric shock.

Table 5.13.4 Trouble Shooting Lighting Systems (cont'd)

STAGE III: MAINTENANCE SURVEY

Equipment required: temperature probe, electric multi-meter, luminance and illuminance meter, polaroid camera.

This stage is based on data furnished by STAGES I and II, but adds more precise measurements and evaluation techniques. The following points should be investigated.

a. analysis of quantity and quality of the electrical supply to all major lighting systems. Resulting data is checked for compliance with applicable performance standards (see Appendices 5.3 and 5.6) and with manufacturer's recommended operational requirements;

b. power factor;

c. analysis of luminaire components for evidence of mechanical, thermal, chemical or other types of deteriorations. This is done by an attentive visual

inspection followed by specific tests as required and generally performed by an accredited independent testing laboratory (see Appendix 5.15). Possible problems involve the following:

- socket deterioration (poor contact, brittleness, arching, loose components, wrong setting or loose setting)
- wiring deterioration (evidence of frying, loose connections, poor anchoring, lack of or faulty grounding)
- deterioration of surfaces (evidence of wear and ultraviolet degradation of reflective transmitting and refracting surfaces, thermal, mechanical, structural or other type of material fatigue, affecting the performance of the luminaire)
- ballasting issues, revealing overheating, wrong match with controlled lamp, (poor installation or location)
- lamp problems revealing: wrong angular mounting; improper or insufficient arc support, especially true for 1000 watt HID and low pressure sodium lamps; exhaustion due to economical end-of-life (defined as the point beyond which it is more economical to replace the still operational lamp than to keep it going); improper match with control gear; improper environmental operating conditions; unsuitability of luminaire, because of size or reflector type or resulting light distribution
- control gear, ranging from the single wall switch to the complex computer control. Here each component is examined for its ability to perform within the manufacturer's specifications and within the needs of the occupant of the space. These two needs should coincide but often may not, because of many reasons, one of which being the dynamic changes of the office space itself and another being the lack of a well coordinated and planned maintenance program, where lamps, ballasts, and control gear have a scheduled maintenance program with properly logged maintenance operations, based on the optimization of economical and technical parameters.

NOTE: Physical surveys may require localized measurements of temperature, voltage, current, power, power factor, illuminance or luminance to determine deviations from expected target values. Long term monitoring may also be required to better evaluate the dynamic aspects of building operations.

5.14 ENERGY AUDIT

An Energy Audit is done to establish the total amount of connected load and its distribution within the building, as well as to estimate, as accurately as possible, the annual energy profile.

There are many software energy management systems available on the market, ranging from the very basic to the most sophisticated. All of them analyze lighting loads as one of the many power/energy inputs and thus require some fundamental data base information related to the lighting, its use, its control and its cost.

This appendix lists the data required for a lighting energy audit and provides a systematic manner to collect it. Documents D04 to D07 of this Series provide details on evaluating energy performance.

FIELD AUDITS

1. Power Rating Identification

   Enter, on a spread sheet, the following information:

   a. luminaire type, make and location;
   b. luminaire wattage rating (inclusive of ballast losses when applicable);
   c. additional luminaire wattage requirements due to aging (up to 25% for LPS, 20% for HPS, 15% for Metal-Halide);
   d. supply information to building energy specialist for analysis.

   NOTE: Energy conservation practices, ranging from lamp disconnection, luminaire re-wiring, use of reduced wattage lamps and use of other energy reducing devices must be observed and logged carefully, then used in the calculation of the total lighting power and energy load. The identification of failed lamps here may not be as important as it is in lighting maintenance, Appendix 5-13, since this is usually a very small load.

   Instruments/equipment required: illuminance meter, electric multi-meter, electric utility rates and bills, reduced set of as-built electrical drawings, list of all luminaires and their power ratings.

2. Operational Light Zones

   Identify zones of luminaires which are operated according to local needs by collecting:

   a. identifying all lighting zones (indoor and outdoor) on plans;
   b. rating total connected load of each zone and listing the identification code next to each zone (e.g.: Zone LP2A-9 [2,560 watt], meaning lighting zone controlled from lighting panel on second floor, LP2, wing A, circuit No. 9, 2,560 watt total load);
   c. estimating annual connected time for each lighting zone, showing typical daily and weekly profiles, as well as unusual profiles such as

overtime and general maintenance requirements. Private offices can be lumped together according to fixed time schedules common to them;

d. indicating illumination level adequacy for each zone, according to visual task needs. (See Appendix 5.9 for visual task rating);

e. indicating if the light zones correspond with the work zones for which they were designed and where shortcomings are located;

f. estimating occupancy profiles for each light zone for the entire year;

g. supplying information collected to the building energy audit specialist for analysis.

NOTE: When conducting energy audits involving lighting loads only, there is the temptation to use the data to generate connected load and energy profiles for the entire building and offer retrofit solutions based solely on such data. This is incorrect as the lighting system is a significant heating load and forms an integral part of the HVAC operation. Any such analysis must include all of the affected building systems.

CREATING A DATA BASE

Many PWC Regions already have a building data base, which include energy profiles of many building within their jurisdiction. Each energy audit can augment this data base and provide more recent information on building energy management trends.

This data file can be constructed to provide load and energy profiles on buildings according to their construction style, insulation and penetration characteristics, heating and cooling modes, client use and other factors.

Several private energy audit consultants have such files and keep them up–to–date to provide accurate predictions to their clients.

SOFTWARE ANALYTICAL TOOLS

These are available both to the private and public sector. No specific recommendations are made here however the accuracy of such tools in lighting energy estimation depend significantly on correct estimation of building occupancy patterns and accurate assessment of required illumination levels.

5.15 PHOTOMETRIC REPORTS, LABORATORY LISTING

INTRODUCTION

Photometric reports are usually prepared by independent testing laboratories, but occasionally can be performed "in-house". There should not be any significant difference between the two services, however independent laboratories have less conflict of interest problems and carry a much larger array of photometric data and for those reasons, are generally preferable. Photometric data is obtained in a laboratory using specific standardized references, conditions of temperature, voltage, and current, and do not represent typical field performance conditions. Some laboratories are equipped to simulate real environments very closely, if requested to do so. Photometric reports are usually done to verify that a particular luminaire performs as the manufacturer claims.

For the purpose of this appendix, photometric testing refers only to representative luminaires which are typical of the installed lighting systems. The sample is field selected, ensuring that a replacement is available, and sent to an independent testing laboratory for a comprehensive photometric report.

STAGE I PHOTOMETRIC REPORTS

Catalogues on lighting products normally carry some form of basic photometric report. These are short versions of full reports, but many provide enough data for an initial evaluation of the luminaire. Technical analysis includes these steps:

a. gather photometric data for each luminaire under examination;
b. compare that the installed luminaires, their background technical data available on file, and catalogue data, all correspond; if they do not, find out where the problem is and act accordingly. Often, imported luminaires are not built to the same specifications as national products, but carry the same photometric report. Beware of this as large performance differences may be found as a consequence;
c. if data available is insufficient, contact the manufacturer and ask for a full set of photometric reports (the manufacturer must have them);
d. check if environmental and operating conditions are within the luminaires specifications (see Appendix 5.6);
e. report any problem to PWC building manager for proper action. This may be to go to Stage II or to demand explanatory statement from the manufacturer, or both.

STAGE II PHOTOMETRIC REPORTS

This requires that a new photometric report be prepared either to verify the depreciation of present luminaires with age or to verify actual performance of installed units.

Follow these instructions:

a. Locate and target typical luminaires for removal and shipment to a testing laboratory; request photometric reports from manufacturer (they should be the same as those on file);

b. indicate type of photometry required: usually a full photometry report;
c. indicate prevalent environmental and operating characteristics and ask for correcting factors;
d. ship luminaire "as is" to the laboratory, not expecting to get it back in working order;
e. compare photometric data on file and new data for significant differences. These are normally found in the dimensions of the luminaire, type of ballast used, type of reflector, lens and finish used. Photometric report differences due to age will provide an overall value for the luminaire efficiency. Differences between reports both applying to new luminaires will point to possible problems in the installation.

STAGE III PHOTOMETRIC REPORTS

This stage is used to assess prototype luminaires. Physical mock-up can be done on site or can be requested from the independent testing laboratory.

Computer generated mock-ups can only be provided by the laboratory and are a preliminary study tool. Follow these steps:

a. engage a knowledgeable consultant with background in this area of expertise;
b. have a consultant prepare a set of specifications to photometrically define luminaire requirements;
c. proceed with field mock-up to ensure proposed units are acceptable;
d. send mock-up to an independent testing laboratory for evaluation. Provide all necessary hardware descriptions, environmental and operative parameters and other pertinent information required;
e. evaluate photometry in terms of luminaire use, quantity and quality of lighting to be delivered, flexibility of control and installation, mechanical and electrical parameters, CSA approvals, maintenance issues, aesthetics and cost issues.

LIST OF INDEPENDENT TESTING LABORATORIES

Contact the companies directly for specific services and costs.

1. Building Acoustics & Lighting Laboratories Inc.
   1618 Headland Drive
   Fenton, Mo. 63026

2. Detroit Testing Laboratories
   8720 Northend Avenue
   Oak Park, Michigan 48237

3. Environmental Research Laboratories (ERL)
   7410 East Helm Drive
   Scottsdale, Arizona 85260

4. Independent Testing Laboratories (ITL), Inc.
   3386 Longhorn Rd.
   Boulder, Colorado 80302

5. Lighting Sciences Canada Ltd.
   440 Philip St., Unit 19
   Waterloo, Ontario N2L 5R9

6. Lighting Sciences Inc.
   7730 East Redfield Rd.
   Scottsdale, Arizona 85260

5.16 COMPUTER AND MODELING STUDIES

INTRODUCTION

Computer-aided design techniques and modeling techniques are the best methods to study the many aspects of the luminous environment.

There is a profusion of tools in both techniques to justify the representation on only the most common ones.

This appendix will treat the computer-based design techniques separately from modeling techniques.

1. Computer-Aided Design Techniques

Following is a list of suggested computer programs recommended because of their overall performance rating including availability, cost, hardware requirements, calculation techniques, flexibility, and user friendliness.

Daylight

*Fenestra
*Daylite
*Controlite
*Sky Component
*Cadlight I

Electric Lighting

*Cadlight II
*CGE Retrofit
*Micro-Cost-Lite
*Lumen Micro
*Micro-Site-Lite
*Flux
*Lecam
*Crew
*Photometric Data Base Converter (from PWC only)
(enquire at PWC/HQ - A&ES - Buildings)
Micro-Eye-Lite
Desige-Lite

Energy

DOE-2.1B,-2.1C
Blast
Merryweather

Under test

Lecam-Crew-Micro (New version)

*Available through PWC A&ES - Buildings (HQ), Ottawa.

Commercially available from various vendors. Contact PWC A&ES - Buildings (HQ), Ottawa for specific details.

Daylight

Microlite 1.0 by Designers Software Exchange, M.I.T. Cambridge, MASS

Daylite 1.0 by SolarSoft 1406 Burlingame Ave., Suite 31, Burlingame, CA 94010
Lumen III by Lighting Technologies, 3060 Walnut St., Suite 209, Boulder, CD 80301
Lumen S by Lighting Technologies, 3060 Walnut St., Suite 209, Boulder, CD 80301
Lumen-Point CAD Lighting Technologies, 3060 Walnut St., Suite 209, Boulder, CD 80301
Lumen-Point by Lighting Technologies, 3060 Walnut St., Suite 209, Boulder, CD 80301
Superlite 1.0 by Windows & Daylight Group, LBL, University of California, Berkely, CA 94720
Micro-Site-Lite by Lighting Sciences Inc., 7830 E. Evans Rd., Scottsdale, AZ 85260
Micro-Eyp-Lite, Design-Lite both by Lighting Sciences
Micro-Site-Lite with digitizer by Lighting Sciences Inc., 7830 E. Evans Rd., Scottsdale, AZ 85260

For more information see the annual listing by IESNA in Lighting Design & Application magazine.

MODELING TECHNIQUES

Physical models are well suited to provide accurate predictions of interior levels and distribution of the available luminous flux.

Models for lighting evaluation can duplicate the full scale building space provided the following rules are observed:

- reflectances in the model are the same as in the real environment;
- the transmission of the glazing material is the same as the proposed glazing;
- the size of architectural and furnishing elements has accurate proportions with respect to the real environment;
- the daylight distribution in the model accurately duplicates actual site conditions;
- photocells are cosine and colour corrected and their size is small in comparison to the model, such as silicon photo-voltaic sensors.

The major advantages of using models are:

- accurate prediction of quantitative aspects, even using crude models;
- accurate prediction of qualitative aspects, if texture of materials used is proportionately the same;
- ease of alternative design evaluation by changing a single design component;
- building and use ease, since they are familiar to most designers.

Physical models can be effectively used under real sky conditions (best under CIE cloudy skies) or under artificial sky conditions.

Real sky conditions (CIE cloudy sky) offer a relatively stable test situation, but best accuracies are not expected to exceed 15%, which, is acceptable for most practical applications.

The artificial sky condition offers a controlled environment where tests can be conducted with greater care and confidence. However the accuracy of results depends on the accuracy of sky replication, model background replication and proportions of model to the artificial sky environment.

In Canada, Concordia University of Montreal and the Technical University of Nova Scotia have the only two artificial skies utilizing mirror boxes.

Better artificial skies are available in the USA at Lawrence Berkeley Laboratory.

See publication listed in Reference 8 for more details on daylighting modelling.

5.17 BUILDING PERFORMANCE EVALUATION DOCUMENT LIST

Documents in this series have been divided into four classes. Class A documents describe the use of documents in the other three classes. Class B is a catalogue of tests which includes an index and cross reference list. Class C documents provide an overview of the three performance areas and summarize the Class D documents in the respective area. Class D documents contain descriptions of performance attributes and detail means of assessing those attributes.

	A1	Project Manager's Guide
	A2	Property Manager's Guide
	B1	Catalogue of Tests
Overviews	C1	Environmental and Energy Performance
	C2	Functional Performance
	C3	Systems and Material Performance
Environmental and Energy Performance	D01	Pollutant Evaluation
	D02	Pollution Migration
	D03	Thermal Environment Evaluation
	D04	Global Evaluation: Energy Performance
	D05	Component Evaluation: Energy Performance
	D06	Equipment and Systems Evaluation: Energy Performance
	D07	Retrofit Evaluation: Energy Performance
	D08	Acoustic Environment Evaluation
	D09	Air Circulation Evaluation
	D10	Illumination Evaluation
	D11	Weather Data Collection
Functional Performance	D20	Record and Archive Analysis
	D21	Plan Annotation
	D22	Focused Interviews
	D23	Questionnaires
	D24	Observation
Systems and Material Performance	D30	Structural Walls and Columns: Condition Survey
	D31	Structural Slabs and Roofs: Condition Survey
	D32	Parking Garages: Condition Survey
	D33	Mechanical Systems Evaluation
	D34	Mechanical Controls Evaluation
	D35	Electrical Systems Evaluation
	D36	Airtightness and Pressure Monitoring
	D37	Measurement of Outdoor Air Supply Rate
	D38	Thermographic Inspections of Building Enclosures
	D39	Thermal Resistance Measurement
	D40	Moisture Content Inspections
	D41	Roofing Systems Evaluation